The WELDING JOURNAL

AUGUST 1953

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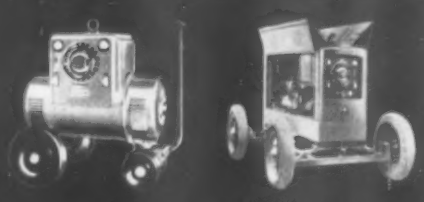

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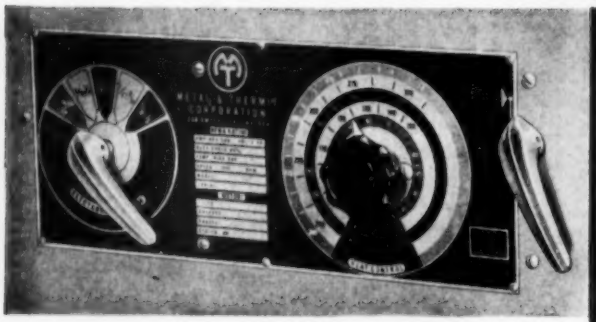

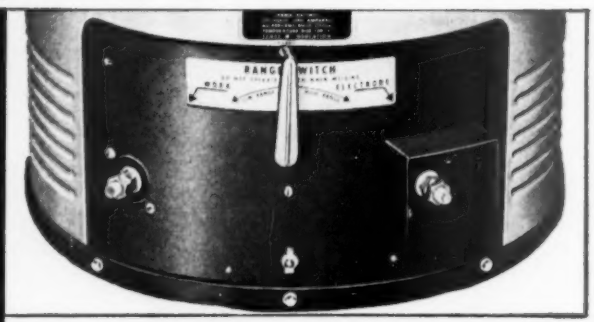

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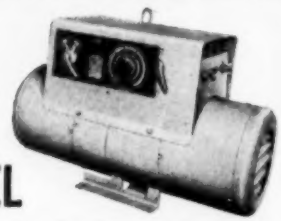

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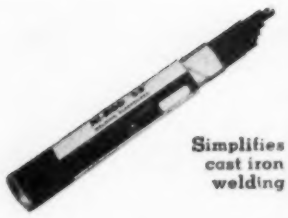

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The WELDING JOURNAL

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Inert-Gas Metal-Arc Welding of Mild and Low-Alloy Steel

Aircraft quality mild and low-alloy steels having controlled surface finish, grain size and physical properties may be successfully welded by the inert-gas metal-arc-welding process

by Frank G. Harkins

INTRODUCTION

THE inert-gas metal-arc process has been highly successful in the fabrication of most weldable aluminum and high-alloy materials. It has been eminently successful in joining dissimilar metals. For example, carbon steel may be welded to stainless steels using austenitic electrodes, such as AISI Type 310 (25 Cr–20 Ni). The application of this process to mild and low-alloy steel, however, is highly controversial. Some users report acceptable results, while others claim that the process is not applicable.

In the automotive field one manufacturer is employing 43 installations in daily production on mild steel parts. In our shop 5 units are in daily production of aircraft parts. Two of these machines are employed exclusively on mild steel fabrications. It must be appreciated that in aircraft fabrication inspection standards are much more rigid than those of commercial users. It may be stated, however, that for aircraft quality welds the application must be approached with caution.

DISCUSSION

Most of the aircraft quality steels are amenable to the process, but many commercial grades are not quite satisfactory. The term "aircraft" quality refers to a steel in which special precautions have been taken to assure the best possible quality in the finished product. Factors such as careful selection of scrap, heating, melting, refining, billet conditioning, rolling and all other mill operations are closely controlled. Naturally, this extra processing tends to increase the cost. Much of the aircraft steel is made in electric furnaces. This alone improves the quality of the steel, since contamination of the steel by the products of combustion is impossible. Aircraft quality steel usually has a superior surface finish; a controlled grain size and closer tolerances as regards physical properties than commercial steels.

Before discussing the qualifications of the application of inert-gas metal-arc welding, it might be well to briefly review the equipment and the method of operation of the process.[1]

Inert-gas metal-arc welding bears the same relationship to inert-gas tungsten-arc welding that metallic arc welding bears to carbon arc welding. In inert-gas metal-arc welding, a consummable electrode is fed through an atmosphere of argon which contains varying percentages of oxygen. We have found a 5% mixture of oxygen in argon will give consistently good results. The consumable electrode—depending on wire thickness and current—is fed at an average of 280 ipm. Current for ferrous aircraft metals is approximately 250 amp through a $^1/_{16}$-diam wire. An electronic control, which is energized by the preset arc voltage, drives a motor which feeds the electrode, thus maintaining a reasonably constant arc gap. On many applications the automatic control may be eliminated and speed and wire adjusted separately. This method of operation, using what is termed constant potential current supply, appears to offer advantages over the standard motor-generator set.

Figure 1 shows a typical installation of an inert-gas metal-arc equipment. It may be noted from the pic-

Frank G. Harkins is Chief Welding Engineer with the Solar Aircraft Co., San Diego, Calif.

Presented before the Western Metals Congress, Los Angeles, Calif., Mar. 23–27, 1953.

Fig. 1 Typical inert-gas metal-arc machine installation

ture that the operator is not required to wear a welding helmet. The 12 inch x 12 inch No. 12 shade welding glass gives adequate operator protection. This particular operation involves the joining of the flange to the tube on the short nipple of a B-29 exhaust system (Fig. 2). There are 72 of these parts required for each airplane. Because the operating temperature is in the range of 1000–1400° F, this small nipple is considered somewhat expendable. Guaranteed service life is 500 hr. A normal production run on these parts is about 10,000 pieces. This operation was formerly a manual arc application requiring approximately $3^1/_2$ min. Present capacity using the simple tooling shown in Fig. 3 is 5 parts per minute. At this great labor saving, it required only a very few months to pay for the tooling and equipment.

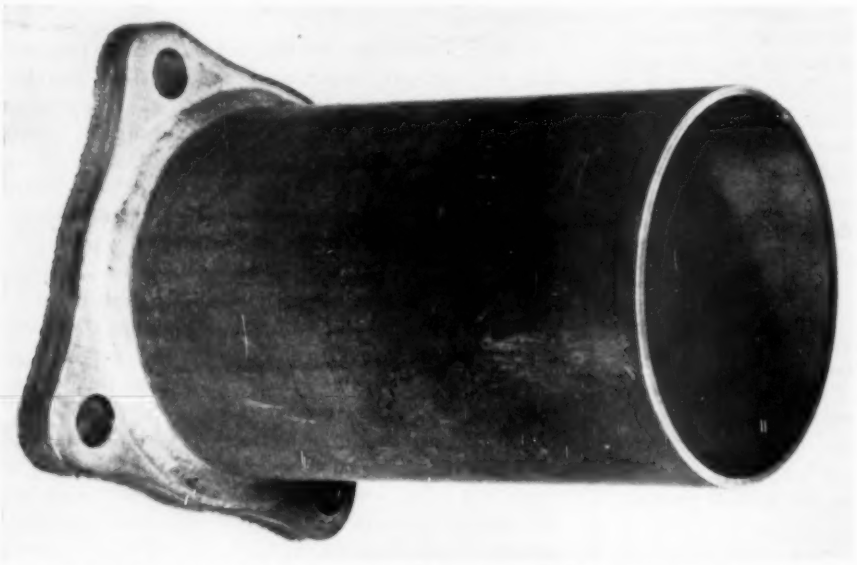

Fig. 2 Sigma welded B-29 nipple. Material is AISI Type 321 stainless steel

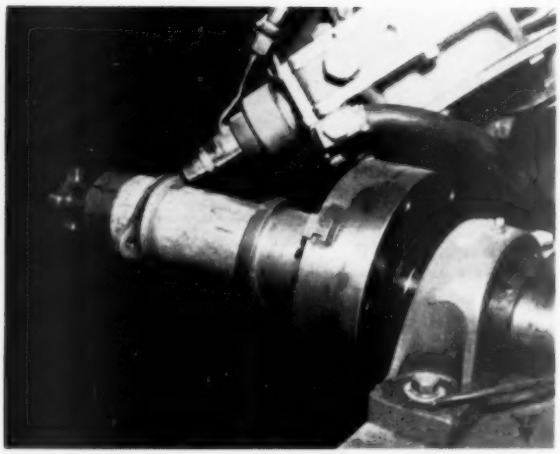

Fig. 3 Fixture for welding B-29 and C-54 nipples

Another installation devoted to an entirely different type of manufacture is shown in Fig. 4. By means of two Solar designed and built fixtures, circumferential welds, which join stainless to mild steel for pipe-line bellows applications, are made at a rate of 96 ipm. In welding large diameters, it is highly desirable to use a rim drive type of mechanism rather than the center drive, since this completely divorces peripheral travel from diameter. The fixture shown in Fig. 4 handles a range of diameters from 5 to 42 in. A closeup of this weld is shown in Fig. 5. The hydraulic elevator type fixture, illustrated in Fig. 6, handles diameters to 14 ft. Cost savings over manual welding is spectacular. Two operators using $^1/_8$ diam electrodes will require approximately 1 hr per joint. The actual welding time for the automatic process is $5^1/_2$ min per joint. Figure 7 shows the 16 welds which constitute entire assembly.

A further application of the process is shown in Fig. 8. This machine makes 4 welds on the J-47 jet engine aft frame cone. This is a special-purpose fixture for a single part, and is, therefore, of different construction than the two preceding fixtures. The welding machine remains stationary, while the work is moved along the track to position the seam beneath the welding head. Should production quantities warrant it, four welding heads could be employed, thus performing the operation in less than one minute. To evaluate the welds in terms of those produced by other commercial processes, Fig. 9 shows a macrograph of a submerged arc weld in Type 321 stainless steel. The large degree of penetration which is characteristic of this process is apparent.

Fig. 4 Simple fixture for welding 5- to 42-in. diam pipes

Figure 10 is a macrograph of the weld on the B-29 nipple, which was shown in Fig. 2. While weld penetration is not nearly so great as that which is obtained from the use of the submerged arc process, it meets existing specifications and is more than adequate for service application.

A manual arc weld using $^{3}/_{32}$-titania-coated electrodes is shown to the left on Fig. 10. Notice that the operator had difficulty in "picking up" the root of the weld.

Fig. 5 Closeup of stainless to mild steel weld

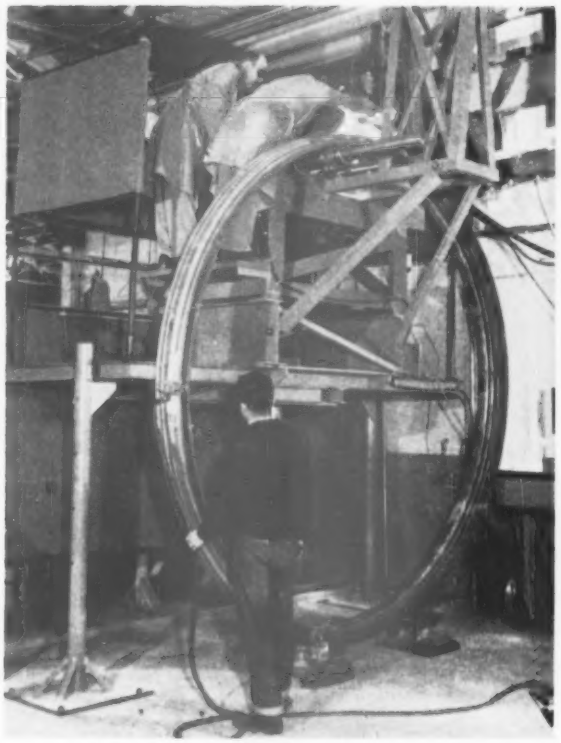

Fig. 6 Hydraulic elevator and simple fixture handles seams to 14 foot diam

As regards penetration, this weld is not comparable to the previously shown automatic welds, although it is adequate for the application.

So far, this discussion has dealt with the commercial application of the process to high quality aircraft materials. As previously indicated, attempts to apply the process to mild steels have met with varying degrees of success or failure as the case may be. In general, the inert-gas metal-arc process may be applied to any metal which may be welded by the inert-gas tungsten-arc process.

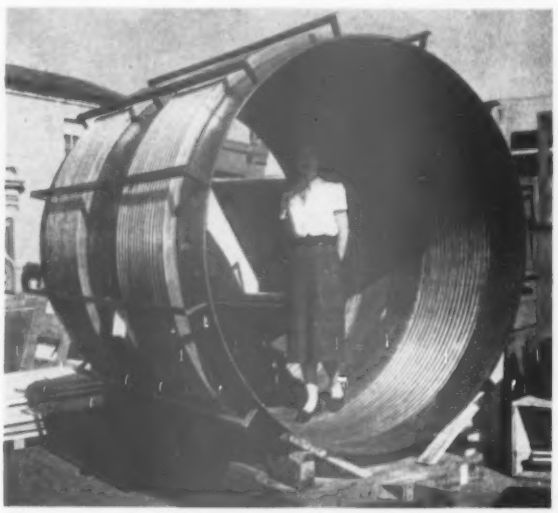

Fig. 7 16 seams on 8-ft diam bellows

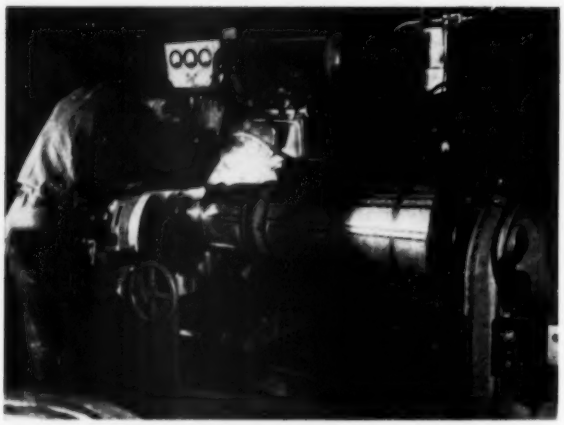

Fig. 8 Special fixture for welding 4 seams low-alloy steel cylinder

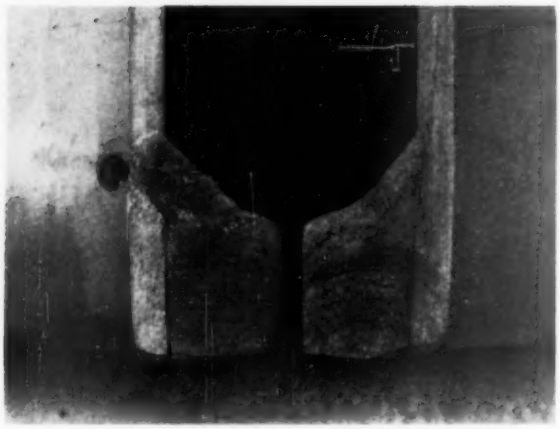

Fig. 10 Macrograph (4 ×) of manual and inert-gas metal-arc weld

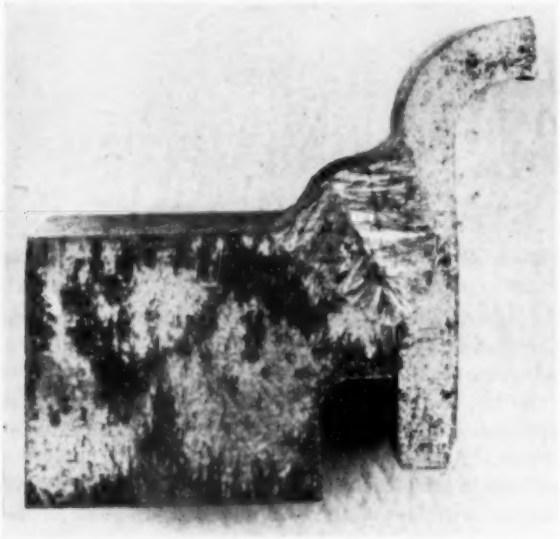

Fig. 9 Macrograph (about 4 ×) submerged arc weld

obtainable in this material, although the mechanical adjustment of the equipment is slightly more difficult.

In welding dissimilar metals, such as stainless to mild steels, our best results have been obtained by using a stainless steel electrode of the AISI Type 310 (25-20). Types 309 and 347 have been employed on special requests from our customers. As a matter of operating principle, however, the most satisfactory

Fig. 12 Chemical analysis base metal and filler wire (chart)

	Base metal	*Filler wire*
Carbon	0.10-0.17	0.12
Manganese	0.50-0.80	1.10
Phosphorus	0.04 max	0.018
Sulfur	0.04 max	0.015
Chromium	0.50-0.75	0.3
Molybdenum	0.15 max	...
Silicon	0.60-0.90	0.22
Zirconium	0.05-0.15	...

Figure 11 is a macrograph of a weld in low-alloy steel. It will be noted that this weld is completely sound. Filler wire is low carbon steel.

Chemical analysis of the base metal and the filler metal is as shown in Fig. 12.

This is an open-hearth steel, but it is automatically killed by the alloy content. It will be seen that several strong deoxidizers are present. Similarly, the low-carbon electrode is fully killed wire. Chromium, manganese and silicon are excellent deoxidizers. Regular low-carbon steel wire may not be employed unless this is made from fully killed steel.

Aircraft quality welds are readily

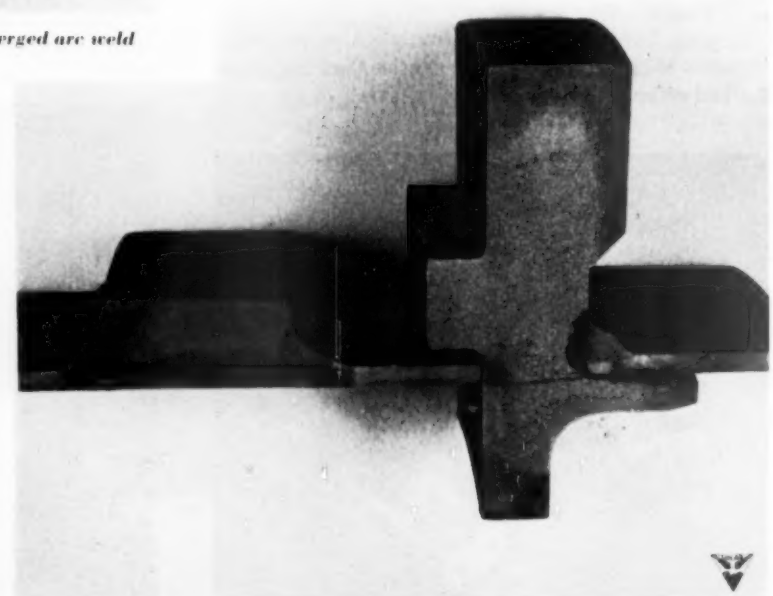

Fig. 11 Macrograph of 3 welds on J-47 cone low-alloy mild steel

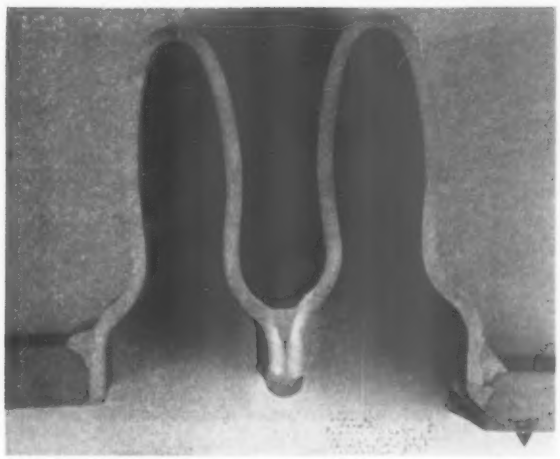

Fig. 13 Macrograph section of bellows showing six inert-gas metal arc-welds

parts are obtained from the Type 310 wire. Most of these applications involve the joining of a heavy walled commercial pipe to relatively thin, approximately 0.063 in., Type 321 stainless steel. The proper technique is to direct the electrode into the mild steel member and allow the weld to "wash" the stainless steel. Figure 13 is a good illustration of the application of the process to stainless and mild steel pipe. There are six welds shown in this specimen. All of these are inert-gas metal-arc welds. Fillet, groove, lap and edge welds are illustrated. The filler wire for the dissimilar metal welds is AISI Type 310, while that which joins the stainless steel members, the groove and edge welds, is AISI Type 347.

The welding of the lower grade steels, such as commercial pipe, using stainless steel wire offers possibilities due to the fact that there is a wide melting temperature differential between the stainless and mild steels, thus minimizing the degree of dilution at the weld interface. A second major advantage of the use of the stainless steel electrode is that the elongation of the stainless material (depending upon composition) may be as high as 60%. Since carbon steels when cooled quickly tend to form hard, brittle structures, shrinkage due to the welding operation will occur in the stainless weld deposit, thus eliminating the tendency toward underbead cracking. Sufficient nickel is present in many of stainless electrode materials to preclude the formation of brittle martensitic alloys in the dilution area. The stainless steels also contain substantial quantities of deoxidizers in the form of chromium, manganese and silicon. These aid in the prevention of gas porosity.

Figure 14 is a macrograph of weld of the bead on plate type using a fully killed electrode, on a fully killed mild steel base metal plate. The shielding gas was 95–5% argon-oxygen mixture. Welding current was 400 amp through a $^1/_{16}$-in. diam wire. It will be noted that this weld is of typical dendritic structure and shows no voids, gas pockets, segregation or other undesirable metallurgical defects.

Fig. 14 Macrograph of "bead-on-plate" test-killed electrode and base plate

Figure 15 is a macrograph of a "bead-on-plate" weld using a semikilled electrode on a rimmed steel base plate. The shielding gas was again the 95–5% argon-oxygen mixture. Welding current was 400 amp through $^1/_{16}$-in. diam electrode. It is possible that the apparent porosity in the "finger" area could have been eliminated or minimized by reducing the current input to 250 amp. Of course, welding costs would be increased at the lower current levels.

Fig. 15 Macrograph of "bead-on-plate" test semikilled electrodes on rimmed base plate

Figure 16 is a macrograph of a "bead-on-plate" weld using a rimmed steel electrode on a rimmed steel base plate. The shielding gas was identical with that used on the previous specimens; welding current was 400 amp through a $^1/_{16}$-in. diam wire. It is felt that welds of this quality are not acceptable by any standards. Reducing the current input would probably alleviate the condition.

Study of the macrographs indicate that in the inert-gas metal-arc welding of mild steels, the use of fully

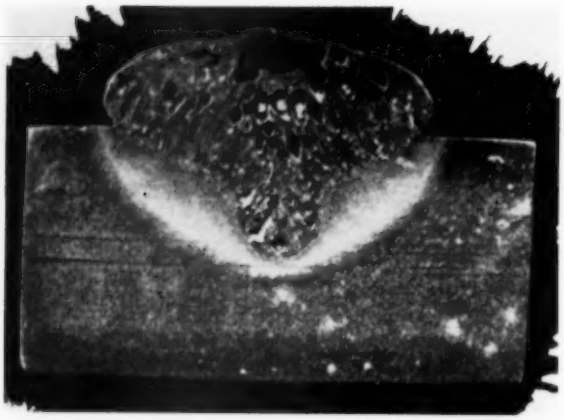

Fig. 16 Macrograph of "bead-on-plate" test rimmed electrode on rimmed base plate

killed electrodes on fully killed base metal will produce the optimum quality welds. Semikilled electrodes may be employed at a sacrifice of quality, while rimmed electrodes are hardly acceptable at all.

It is unrealistic and uneconomical to demand fully killed base plates for the successful application of the process. It has been shown by Warren and Stout[2] that mill practice on the base metal is not nearly so important as that on the eletrodes. As regards suitability of base plates, killed steel produces best results; semikilled steel is rated second, while rimmed steel is last.

Unfortunately, the attainment of aircraft quality welds on mild and low-alloy steels is not as simple as the preceding discussion indicates. There are many other factors which are just as important as the properties of the materials which are obtained as a result of mill practices. Material preparation, mechanical arrangement of the joint, adequacy of the tooling and welding equipment, arc voltage, current, speed of travel, wire feed and bead shape are but a few of these factors. Time will not permit a detailed discussion of these factors.

It has been shown by numerous experimenters that parts to be welded should be clean, free from grease, oil, paint, scale, slag or any other foreign material. Welding on unclean materials usually results in gross porosity, undercutting, rough appearing welds, and in some cases, underbead cracking.

Similarly, the mechanical fit of the joint is extremely important in the procurement of sound defect free welds. A wide gap between the sheets may be tolerated, provided a well fitting support bar is furnished. Should the support bar be illfitting, the situation becomes intolerable, since underbead cracking extending from the root of the weld to the outside surface usually occurs. Fit of the bar cannot be so poor as to allow excessive air to contact the root of the weld.

The inert-gas metal-arc process is adaptable to all of the standard joint designs. From our experience, the following joint types are listed in the order of ease of application: (1) the supported butt weld, (2) the standard lap weld, (3) the right-angle fillet weld, (4) the groove weld and (5) the edge weld.

In fillet welding the most desirable weld bead shape is one in which the surface of the weld bead is approximately a straight line. A slight degree of convexity is satisfactory, while a concave fillet is an indication of excessive energy input and/or a poor welding technique. Concave fillets are generally to be avoided, since they contribute to excessive undercutting and root cracking.

As regards technique in fillet welding, the ideal head position is one in which the feed wire approaches the groove at an angle of 45 deg. In some cases, such as in welding thick to thin members, it is desirable to direct the wire toward the parts of greater mass so as to prevent "burn through" of the thinner member.

It has been observed that the welding technique is just as important as material composition in the welding of mild steels. Porosity also appears to be a function of the mechanical adjustment of the welding head.

If the material is of sufficient mass that relatively low welding speeds at low currents may be employed without the possibility of burn through, the weld puddle may be kept sufficiently fluid to allow any dissolved gas to escape before solidification, thus permitting porosity-free welds. This appears to be the great advantage of the application of the submerged arc process over the inert-gas metal-arc process, because the granular flux blanket allows a sufficiently slow cooling rate, so that much of the gas escapes before solidification of the weld puddle. Paradoxically, however, dilution of the weld metal with the parent material should be minimized.

On a recent application involving a supported fillet weld between two pieces of mild steel, it was necessary to weld only three sample parts before porosity-free welds were obtained. The adjustment of the angle and position of the welding head in relation to the work is somewhat critical on circumferential welds. It has been observed that the best results are obtained when the welding head is at an angle of 80 deg in relation to the horizontal plane of the work. This gives gas protection to the solidifying metal and allows the operator to constantly observe the weld as it is being made. The welding head is placed at the 11 o'clock position, and its angle points to the direction of the rotation. Through the use of this technique, a large measure of porosity, which ordinarily might occur, is eliminated.

A discussion of this nature would not be complete without some reference to the characteristics of the welding generator. The standard 600-amp generators which employ integral excitation have not been satisfactory for long seams. The separate excitor type of generator is highly desirable, since this allows ease of conversion to the voltage-regulated type of operation.

At the present state of development of the application of the process in our plant, best results have been obtained by means of the constant potential type generators. Through the use of this type generator, the arc voltage does not vary appreciably during the en-

tire weld interval. This allows the operator a good measure of control over the weld puddle and results in a lowered tendency toward undercutting.

On the basis of early experience with the selenium-type rectifier welders, these appear to have decided advantages over the standard motor-generator set. Without the constant potential attachment on standard rotary-type equipment, the amperage tends to drop off as the weld progresses, especially on long seams. This phenomenon has not been observed when using the selenium rectifier-type equipment. If anything, the weld current appears to increase slightly as the weld progresses. It is our opinion that the selenium rectifier-type equipment in combination with a constant potential device represents the ultimate in power supply for this welding process.

SUMMARY AND CONCLUSIONS

To summarize the discussion, it may be stated that the inert-gas metal-arc process is capable of producing completely satisfactory welds in stainless and high-grade low-alloy steels. Most aircraft steels fall into these categories and, therefore, few welding difficulties may be expected. The applicability of the process to low-grade mild steels will be conditioned by the degree of metallurgical defects which may be acceptable for the intended use of the part. In most cases for commercial products, the use of a fully killed electrode is recommended. A high-grade stainless steel electrode will generally produce sound welds in mild and low-alloy steels, but care must be exercised in the application of the stainless steels to the carbon steels if a hard underbead interface is to be avoided. Use of semikilled or rimmed electrodes is not recommended. In joining stainless to mild steels, the use of a stainless steel electrode is mandatory. Best results are usually obtained when using relatively low welding speeds at low currents. The current and speed are of course, functions of the mass, geometry and specific heat of the material being welded. As far as is practical, the degree of dilution of the weld metal by the base material should be minimized. The mechanical arrangement of the equipment is an important factor in minimizing welding defects. The use of constant potential generator appears to offer many advantages over the conventional type equipment, especially on long seams.

ACKNOWLEDGMENTS

The writer wishes to acknowledge as sources for some of the information contained in this report, papers by H. T. Herbst, Linde Air Products Co.; Donald Warren, E. I. Du Pont de Nemours & Co., Inc., and R. D. Stout of Lehigh University. Credit is also due to H. C. Thompson and A. M. Frohn, Weld Technicians, Solar Aircraft Co., for the preparation of the photographs and weld specimens which were used as illustrations.

Bibliography

1. Herbst, H. T., and McElrath, T., Jr., "Sigma Welding of Carbon Steels," THE WELDING JOURNAL, 30 (12), 1084-1091 (1951).
2. Warren, Donald, and Stout, R. D., "Porosity in Mild Steel Weld Metal," *Ibid.*, 31 (9), Research Suppl., 406-s to 420-s (1952).

Relation Between Welding Current and Appropriate Transmission of Filter Glasses

Formula outlined for determining the most suitable transmission of the filter glass for a given welding current

by T. Rosskopf

INTRODUCTION

THE importance of the use of appropriate filter glasses to protect the eyes during welding is universally recognized.

In the U. S. Federal Specification for "Welders Helmets" GGG-H-191a, a standard classification for filter glasses is given, the shade Nos. 8 to 14 being especially intended for arc welding. The Notes of this specification give the limits of welding currents for which the different shade numbers are intended. These limits are only specified for the even-numbered shades, but as the classification includes also the uneven-numbered shades, different manufacturers of filter glasses furnish also the uneven numbers.

In this article a formula will be outlined giving, under

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certain restrictions, the most suitable transmission of the filter glass for a given welding current. By this formula the questions can be answered whether it is of importance to use also the uneven-numbered shades and which of the shade numbers is the most appropriate for medium-sized welding work.

IDEAL TRANSMISSION FOR GIVEN WELDING CURRENT

In the arc a certain quantity of heat and radiation is produced. For a given type of electrode the ratio between the radiated and the total energy may be represented by a constant factor. This factor and the total energy, however, vary for different classes of electrodes, depending upon the arc length and the composition of the coating. The limits given in the Federal Specification for the welding currents for a given shade can, therefore, only be applicable for a certain type of electrode. It may be supposed that these limits are valid for general welding work using ordinary (high class) electrodes, and we have accordingly based our investigation on the properties of a heavy-coated iron-oxide electrode complying with the requirements of AWS and ASTM class E6020 and E6030, and giving a weld with a tensile strength of 30–32 ton/sq. in. and an elongation ($l = 5d$) of 28–34%. For this electrode the relation between the arc voltage E_a and the welding current I can be expressed by the following equation.

$$E_a = 21 + 0.035I \qquad (1)$$

This equation gives for a welding current of 100 and 300 amp an arc voltage of 24.5 and 31.5 v respectively. The power P_a consumed in the arc can be taken as proportional to the product of the arc voltage and the welding current, hence

$$P_a = C_1 \times E_a \times I = C_1 I\,(21 + 0.035I) \qquad (2)$$

The radiation energy per sec is proportional to the power and for a given permissible dosing of the eye the transmission of the filter glass is inversely proportional to the radiation and consequently to the power P_a, hence

$$T_i = \frac{C_2}{I\,(21 + 0.035I)} \qquad (3)$$

We call T_i the ideal transmission as, for a given dosing of the eye, the transmission calculated according to eq 3 gives the most suitable value for a given welding current. However, the actual values can only be obtained when the factor C_2 is known. This factor can be determined when for one value of the welding current the ideal transmission is known.

According to the Federal Specification, shade No. 10 is recommended for currents ranging from 75 to 200 amp and shade No. 12 for currents ranging from 200 to 400 amp. We may therefore conclude that the ideal transmission for a welding current of 200 amp is equal to the standard visible transmission for shade No. 11, being 0.0052%.

According to the British Standard 679: 1947 for "Protective Filters for Welding," the shade No. 11 is recommended for welding currents ranging from 100 to 300 amp for indoor welding. For the visible radiation the classification of the shades in the British Standard is the same as in the Federal Specification. Therefore according to the British Standard also the ideal transmission for a welding current of 200 amp can be taken to be 0.0052%.

For this value the factor $C_2 = 29.12$, and eq 3 can be converted to:

$$T_i \text{ in } \% = \frac{29.12}{I\,(21 + 0.035I)} \qquad (4)$$

For a given value of T_i the corresponding welding current can be calculated by the following formula:

$$I = 100\left(-3 + \sqrt{9 + \frac{0.0832}{T_i \text{ in } \%}}\right) \qquad (5)$$

In these calculations we have taken into consideration only the visible radiation. The transmissions for the ultraviolet and infrared rays of filter glasses, especially manufactured for the purpose of protecting the eye, are extremely low. For a glass complying with shade No. 10 a transmission of 0.0004% was measured for a wave length of 365 millimikron, and a transmission of 0.0014% for a wave length of 1000 millimikron, i.e., lower than the limits of 0.05 respectively 0.3% specified in the Federal Specification for the darkest shade, No. 14. Therefore it is not necessary for the purpose of this article to take into consideration the transmissions for the non-visible radiation.

GRAPHS

In the curve of Fig. 1 the ideal transmission according to eq 4 is plotted. Moreover in this figure the limits for the current and transmission for shade Nos. 10, 12 and 14 according to the Federal Specification are shown. As can be seen by studying Fig. 1, the recommended limits deviate considerably from the curve of the ideal transmission.

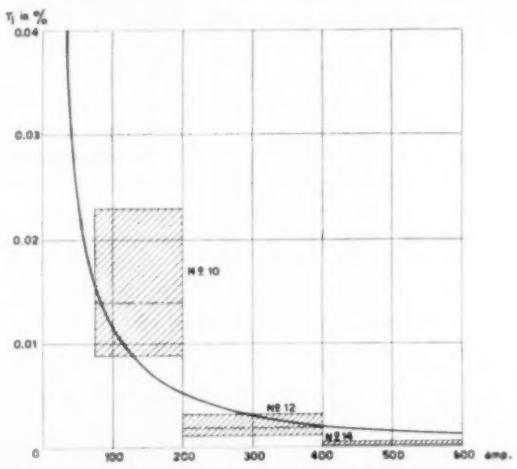


Fig. 1 Classification according to U. S. Federal Specification

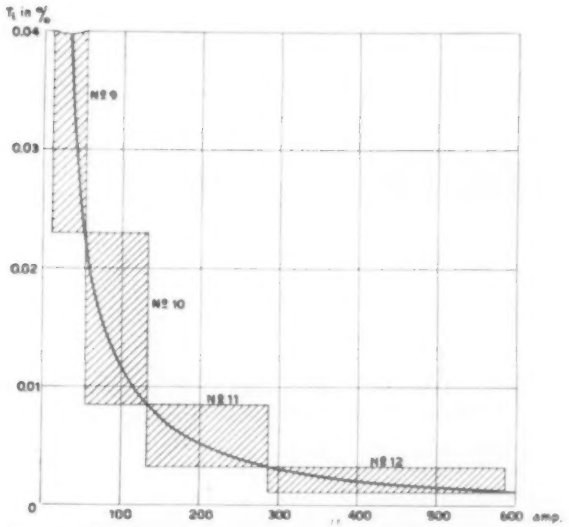


Fig. 2 Classification according to ideal transmission curve

By using both the uneven and the even shade numbers and by taking appropriate values for the welding current, a perfect adaptation of the classification to the ideal transmission curve can be obtained, as shown in Fig. 2.

TABLE 1

Successive shade numbers	*Transmission between shades, %*	*Calculated welding current, amp*
8–9	0·061	22
9–10	0·023	55
10–11	0·0086	132
11–12	0·00325	288
12–13	0·00119	588

Table 1 gives the values of the welding current for the transmission between two successive shades, calculated by means of eq 5.

Allowing some overlapping for the values of the welding current, Table 2 gives the limits of the welding current for the different shade numbers.

TABLE 2

Shade No.	*Welding current, amp*
9	20–60
10	50–140
11	125–300
12	275–600

CONCLUSIONS

1. The filter glass according to shade No. 11 must be given a special place in the range of glasses. This shade is appropriate to be used for general welding of medium-sized work with electrodes ranging from $^1/_8$ to $^1/_4$ in. (125–300 amp). Practice has shown that this shade number can be used for 70% of all arc welding work.

2. If only the even-numbered shades are used, the welder has to switch over from No. 10 to No. 12 at 200 amp, a current region in which most welding is done and where a sudden drop in visibility is most undesirable.

3. The application of both the uneven- and the even-shade numbers means a finer graduation, making further selection between glasses of the same shade number unnecessary.

NATIONAL FALL MEETING
AMERICAN WELDING SOCIETY
Hotel Cleveland, Week of Oct. 19th
In Conjunction
National Metal Congress and Exposition
Technical Program Published July Journal
Latest Revised Program to Appear in Sept. Issue
Plan to Attend

Stranded Electrode Materials for Aircomatic Welding

This type of electrode seems to be the answer where certain desirable compositions cannot be swaged down to small diameter wires and coiled on spools

by Harold Robinson and Harry C. Cook

INTRODUCTION

THE inert-gas-shielded metal-arc consumable electrode process is a fusion welding process in which the arc is shielded with argon, helium or mixtures of these gases. The filler wire is the electrode and is fed continuously by a constant feed motor drive to a manual directed gun or automatic head from a 10- or 25-lb spool of wire. Two distinctive and important features of this process are continuous semiautomatic wire feeding and projected metal transfer. The process employs a continuous length of small diameter electrode wire ($^3/_{64}$ to $^3/_{32}$ in.). High arc-current density is imposed upon the small diameter wires and relatively high welding currents are used. The current density for this process is approximately nine times greater than that used for conventional coated-electrode welding. Figure 1 shows a photograph of the manual equipment.

The production of small diameter continuous length wires of the conventional welding materials is no particular problem for this process. Most of these wires are supplied at a nominal cost, cleaned, straightened and spooled, ready for welding. There is a rather large field of fusion welding which has to do with the overlay of special composition materials which have certain desirable properties, i.e., corrosion resistance, hardness and bearing properties. In many cases, these materials are difficult or impossible to manufacture in small diameter wires. Where this is the case, it is customary to manufacture the welding materials in rather large diameter short length rods, cast or swaged to shape, to be used as filler rods, inserts or coated electrodes. There are many desirable compositions which, even if possible to swage down to small diameter

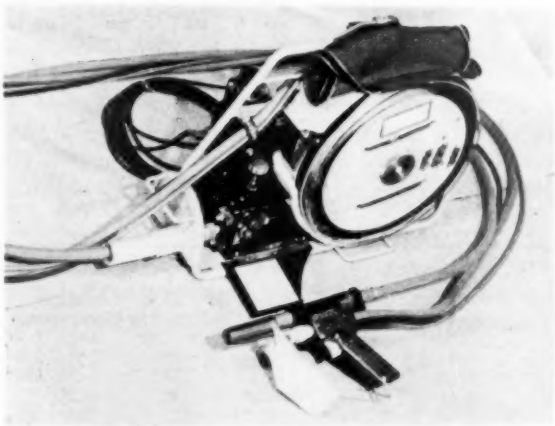


Fig. 1 Aircomatic model 20 manual gun and carriage assembly

wires, could not be coiled on spools because of their extremely low ductility. Aluminum bronze, when the aluminum content exceeds 10%, is such an alloy. The commercially useful aluminum bronzes with a high aluminum content undergo a very expensive series of swaging and annealing operations which preclude their economic production in the small sizes and continuous lengths required by the Aircomatic* process. Many other hard-facing materials fall into a similar category and are also not available for this process.

THE COMPOSITE ELECTRODE WIRE

A study of the composition of these special materials shows that the elements making up some of these alloys are very ductile and workable, particularly those which do not contain carbon as a hardening element. This observation suggested the possibility of making small diameter electrode wires by compositing the ductile elements. Aluminum bronze was considered for this approach. First, the excellent properties of aluminum bronze make it a popular and useful alloy for many types of overlay and joining applications. Second, aluminum bronze has equal or better weldability with the con-

Harold Robinson was formerly with the Air Reduction Research Laboratory, and **Harry C. Cook** is connected with the Air Reduction Research Laboratory, Murray Hill, N. J.

Presented at the National Spring Meeting, AWS, Houston, Tex., June 16–19, 1953.

* Aircomatic is the Registered Trade Mark for inert gas welding equipment sold by the Air Reduction Company.

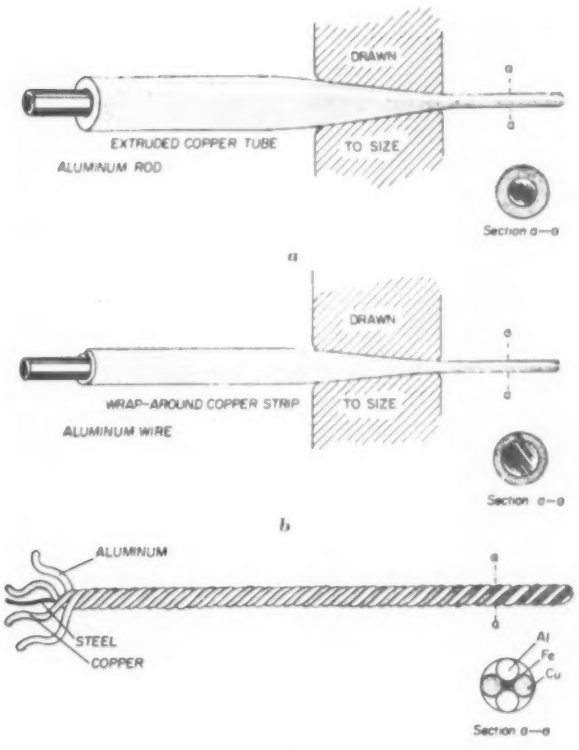


Fig. 2 Possible methods for fabricating aluminum bronze electrode wire

sumable electrode inert gas welding process than any other material employed. It was felt that as this became more widely known, the demand for this material would increase. Finally, the elements of this alloy, high purity copper, aluminum and iron are very ductile and commercially available at relatively low cost.

FABRICATION METHODS

The question was how to fabricate a small diameter composite electrode. Three methods suggested themselves as being both commercially practical and economical. These are shown in Fig. 2. Aluminum bronze composite electrodes were actually made by all three methods. In Fig. 2, method (*a*), a high purity copper tube, in which a bar of 2S aluminum was placed, was extruded. This composite was then rolled and drawn down to $^1/_{16}$ in. diam wire. The resulting wire produced an excellent welding electrode and demonstrated that the proposition of composite electrodes for the Aircomatic process was practical. Method (*a*) was eventually discarded because of the manufacturing length limitation and the difficulty of introducing a third element. Making the necessary iron addition by alloying with copper or aluminum reduces the ductility of these alloys and required the casting of special alloy heats. This would defeat the advantage of manufacturing simplicity which the composite method offered.

Method (*b*) appeared to offer some promise since it is not difficult to roll-form a copper wrapping around an aluminum wire core similar to the method used for fabricating several of the ferrous hard-facing materials. Continuous lengths are easily made and the composite can be readily drawn down to suitable sizes. This method also presents the difficulty of introducing a third element. If a fine iron wire were added to the core of the method (*b*) composite, we could not depend upon the iron wire to draw down in the same proportion as the copper and aluminum. Neither of the above methods were considered flexible enough to permit economic changeover for the different sizes and compositions in the comparatively small lots which the industry requires at the present time.

The stranding method (*c*) seemed to overcome the objections of the above methods and is now being used to manufacture electrodes commercially. A number of copper aluminum and iron wires of the proper diameter are stranded together to the final size producing a composite electrode, $^5/_{64}$ in. in diameter. In the aluminum bronze compositions, the iron, being in the form of a very fine wire, is placed in the center of the strand to protect it from premature melting and unraveling from the radiant heat of the welding arc. The strand of the composite is designed to give maximum stiffness consistent with other requirements of the process. There was considerable skepticism regarding the ability of this "rough string" to properly feed in the semiautomatic equipment. With some of the original stranded samples, it turned out that this skepticism was well justified. These difficulties were subsequently overcome with improved strand designs. The smallest diameter composite electrode made at the present time is nominally $^5/_{64}$ in. The true cross section area of this electrode is about the same as a $^1/_{16}$-in. diam solid wire. The $^5/_{64}$ in. diam was selected to give the electrode additional section modulus which improves its feeding ability through the gun. Smaller diameter

Table I—Stranded Electrode Wire

Components of electrode			*Composite-electrode*	
Element	Purity, %	Impurity, %	ASTM specification for ECuAl-B(B225-52T)	Probable impurity present in composite-electrode deposit %
Aluminum—EC	99.90*	0.10	11.0-12.0 (11.5%)	0.012%
Iron—AISI 1005	99.40	0.60	3.0-4.25 (4.0%)	0.024%
Cooper—ETP	99.98†	0.02	Rem. (84.5%)	0.017%
			0.60% max total impurities (including Si)	0.053% total impurities (including Si)

* Aluminum plus iron plus copper.
† Copper plus silver plus oxygen.

stranded electrodes are not available because they are excessively flexible and present feeding difficulties at this time.

PURITY OF COMPOSITE ALUMINUM BRONZE

In the case of aluminum bronze, the components are made from extremely pure materials which fortunately are available as standard mill products; electrolytic tough pitch copper, electrical conductor aluminum and low-carbon steel. An example of an aluminum bronze composite electrode with an analysis conforming to ASTM B225–52T, ECuAl-B is shown in Table 1. This electrode will have maximum total impurities of about 0.05% as compared with the specification maximum of 0.60%. The discussion of electrode purity in Table 1 is based on nominal compositions for the component elements which are used in the form of commercially drawn wire. (The values of "Per Cent Impurity in Composite Electrode," column 5 of Table 1, are the products of columns 3 and 4.) The copper, which makes up about 85% of the composite electrode composition, is electrolytic tough pitch copper. This material has a minimum guaranteed purity of 99.9%. In actual practice, the purity runs about 99.95%. The major impurity present in ETP copper is oxygen present as dissolved copper oxide. This may be present to about 0.03%. Since the oxygen will combine with the aluminum during deposition, it will not appear as an impurity in the deposit. This leaves a total impurity of 0.02% in the copper consisting of trace elements and sulfur. EC aluminum, which is used for electrical conductors, has a minimum aluminum content of 99.45%. The 0.55% balance is essentially iron plus silicon plus copper. Since iron and copper are major alloy additions for aluminum bronze, they cannot be considered impurities. This leaves about 0.10% impurity in EC aluminum, most of this being silicon. The balance in a rimmed AISI 1005 steel consists of manganese, carbon, phosphorus, sulfur and small amounts of residual elements from scrap addition. These may total up to 0.60%. Surprisingly enough, this represents the largest source of impurity. Ingot or wrought iron wire could be used to reduce this amount if it were considered necessary.

The stranding method is very flexible, changing from one alloy to another being simply a matter of drawing the individual wires to the proper diameter and setting the stranding machine for the predetermined strand design. The composition of such a composite-electrode is constant throughout its length and from spool to spool, completely independent of ingot segregation or variations between heats.

COMPOSITIONS

Another group of copper alloys which lend themselves to the stranding operation is the high lead-tin-copper bearing materials. For bearing overlays or for repairing cast bearings, this material is normally cast in heavy rods—up to 1/2 in. diam for carbon-arc or bare electrode application. With the composite method, an extruded lead-tin solder wire is made the core and surrounded in the strand by several fine copper wires. The soft solder core is so completely enveloped by the copper that it does not melt until it enters the arc, at which time the copper and core wires melt and mix uniformly.

The stranded compositions presently being offered commercially for the Aircomatic process are shown in Table 2. Along with these are listed aluminum bronze electrodes of intermediate compositions which may, at some later date, have particular commercial application. The complete list embraces the entire range of aluminum content from the structural alloy of 9.25% aluminum up to the hard wear-resistant surfacing alloy containing 14.5% aluminum. The intermediate compositions produce deposits of progressively increased hardness. The Brinell hardness ranges which can be expected in service applications are also given in Table 2. In the case of application as a structural filler material, the hardness as well as the strength and ductility will depend to a certain degree upon the base metal composition and the amount of mixing between this base metal and the filler material. This brings into account welding techniques as well as welding conditions.

In all of the work with inert-gas consumable electrode welding it has been found that the amount of elemental loss in the arc is very much less than that experienced in the metal-arc process. This results in a higher aluminum content in deposits made with the inert-gas process than would be obtained with the same aluminum bronze electrode composition in the metal-arc process. For this reason, the aluminum content of the

Table 2—Stranded Electrodes for Aircomatic Process

5/64-in.-diam spooled electrode wire

Airco Alloy No.	ASTM specification*	*Nominal Composition, %* Al	Fe	Pb	Sn	Cu	*Brinell (3000 kg) expected service ranges*
A101†	B225–52T, ECuAl-A_2	9.25	1.0			Rem.	110–150
A120	No existing specification	10.75	4.0			Rem.	160–190
A161†	B225–52T, ECuAl-B	11.75	4.0			Rem.	210–240
A125	No existing specification	13.0	4.0	..	..	Rem.	260–280
A190†	No existing specification	14.30	4.0	..	..	Rem.	310–350
A170†	B144–52, 3D	...	..	14.5	6.5	Rem.	...

* Deposit meets requirements.
† Commercially available.

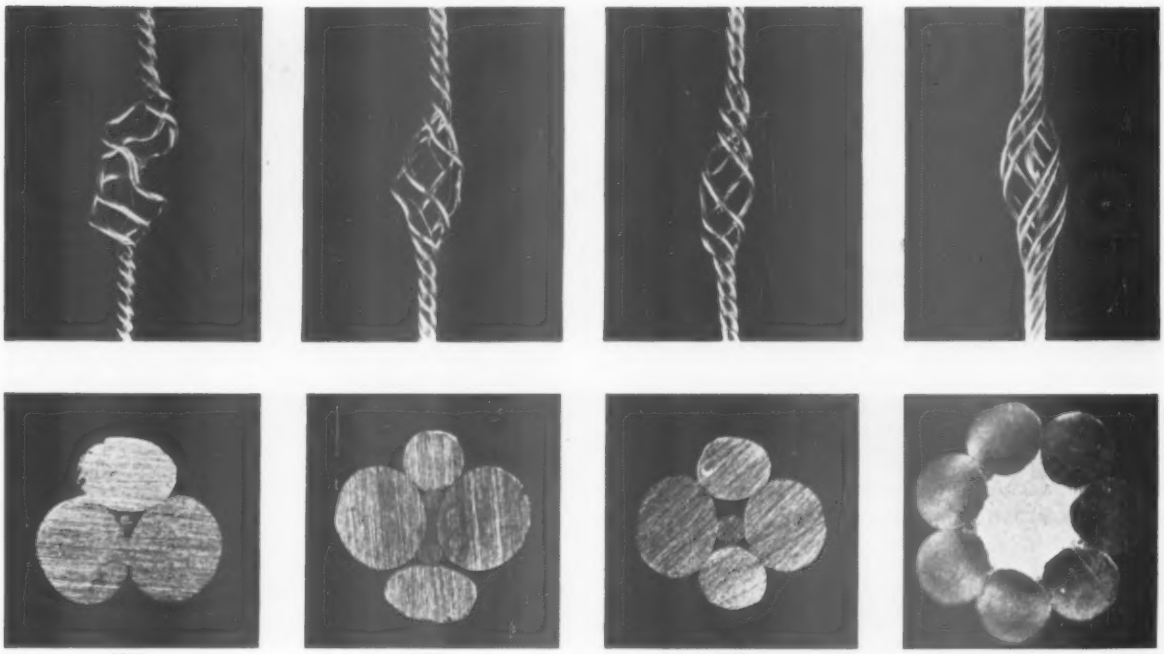


Fig. 3 Construction of stranded Aircomatic electrodes

stranded aluminum bronze electrodes are below that found in corresponding metal-arc electrodes. The efficiency of depositing these alloys is also much better in the case of the inert-gas consumable arc process over other methods of depositing alloys of these types since the spatter loss and stub-end loss are reduced to a minimum.

CONSTRUCTION OF STRANDED ELECTRODES

Figure 3 is a series of photographs which show the construction of four stranded composite electrodes. These have been enlarged to show in greater detail the position of the separate strands. The separate wires are in contact with each other and form a tight and compact cable. The elliptical appearance of the strands is due to the sectioning of the spiral wire and not a result of deformation after stranding. The first three wires shown are aluminum bronze materials as listed in Table 2, the last is the leaded bronze composite. The aluminum bronze electrodes are composed of strands of each of the separate constituents of the particular alloy composition. There are physical requirements as well as chemical which must be fulfilled by the stranded electrode in order that it be useful in the consumable electrode, inert gas welding equipment. It is necessary that the composite be so constructed that it will pass through the feeding mechanism of the equipment smoothly without binding or snagging. This requires that the stranded electrode must be: (1) Tight and present a uniform surface so that it can pass through the feed rolls without being distorted; and (2) present a smooth, nonbinding surface in order for it to pass through the inner connecting liner to the gun and eventually pass smoothly through the current pick-up tube into the arc.

To accomplish this has necessitated the correct balancing of strand size and twist in order that: (1) The strands are structurally stable and will not move under pressure; and (2) the copper strands are higher than the aluminum strands to prevent galling in the lining and current pick-up tube. (The iron wire is, of course, quite small and is necessarily in the center of the stranded composite to prevent it from burning off too rapidly during welding.)

In order to fulfill all of these requirements in the three compositions of aluminum bronze shown, it is necessary that three separate strand designs be employed. The A101 electrode is composed of two copper strands, one aluminum strand and one fine iron strand in the center. The difference in density between aluminum and copper is fortunate, since to obtain the required 9.25 weight per cent aluminum in the composite, the aluminum strand due to its lower density, is almost the same size as a copper strand. In Fig. 3, A101, the aluminum strand is in the 12 o'clock position.

The A161 electrode is composed of two aluminum strands in the 12 and 6 o'clock positions, two copper strands and two fine iron strands. In this case, it was necessary to use two smaller iron strands in order to produce a structurally stable composite. The A190 electrode is composed of two aluminum strands in the 12 and 6 o'clock positions and two copper strands. It was again feasible to use the single iron strand in this electrode.

The A170 leaded bronze composite electrode utilizes a core of 70% lead 30% tin alloy around which strands

of copper are closely wound. As can be seen, the soft core has been deformed during the stranding and conforms to the inner surfaces of the surrounding close-packed copper strands. This was necessitated by the requirement that the electrode withstand the drive roll pressure without damage. The resulting stranded composites as seen in Fig. 3 fulfill all the requirements of electrode materials for this process.

WELDING CHARACTERISTICS OF STRANDED ELECTRODES

The distinct advantages of the inert-arc consumable electrode welding process over other methods of depositing nonferrous materials are: increased over-all deposition rate, increased deposition efficiency, reduction in loss of alloy elements, lack of surface flux and entrapped flux materials, freedom from porosity, smooth and more uniform bead surface and ease of application.

These advantages are the result of what occurs in the welding arc within the inert shield. The inert gas obviously prevents oxidation of the electrode constituents as they melt, pass through the arc and solidify. As the current density employed in this process this transfer consists of small droplets which pass through the arc plasma very rapidly. The size of the drops is inversely dependent upon the current density in the argon arc. In the case of aluminum bronze stranded electrodes this is a fairly uniform stream. For the conditions usually employed, that is, reverse polarity, 260 to 290 amp at 27 to 28 arc volts, they are in the form of drops about $^1/_{16}$ in. in diameter. These conditions result in deposition rates of 9.5 to 11 lb per hour. The current must be lowered to 240 to 250 amp in the case of the leaded bronze electrode since the melting point of the alloy is lower and overheating will result in increased lead loss.

Motion pictures taken with a high-speed camera show the composite electrode being melted down uniformly into homogeneous drops which are projected across the arc in a continuous stream to produce a uniform bead deposit. Figure 4 shows such a homogeneous drop which was being formed as the welding arc was extinguished.

Fig. 4 Drop of homogeneous aluminum bronze formed on a stranded electrode in the Aircomatic arc

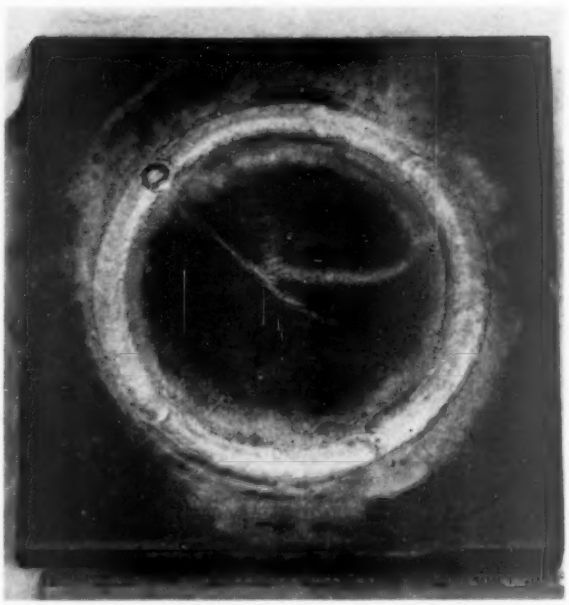
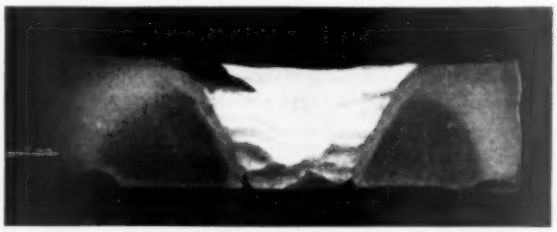
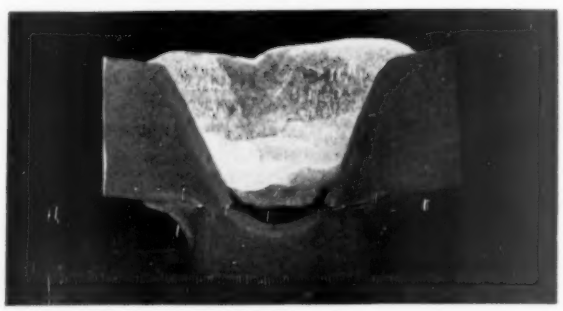


Fig. 5 Aluminum bronze restrained patch test plate—$^3/_8$-in. Grade 8, weld wire Airco A101. Radiographic examination shows an occasional hole but no cracks

The cleanliness of the bronze deposit and its surface appearance is dependent upon the surface on which the weld is made. It is, therefore, necessary to remove any scale or oxide on the surfaces prior to welding. The



Stringer bead technique



Split weave technique

Fig. 6 Macrostructures of welds made with A101 stranded electrode using different welding techniques

usual methods employed are rough grinding or sand-blasting of the parts before welding.

When helium is employed as a shield, the arc is more erratic and the transfer is not so uniform as it is in an argon shield. This results in a rougher bead appearance with increased spatter. As with other electrode materials, helium-argon mixtures can be employed as the shielding gas.* An 80–20 helium-argon mixture provides a satisfactory compromise of arc stability and bead appearance. The use of helium-argon mixtures and helium in particular is more of a compromise in the case of the stranded electrodes since superior results are obtained with argon both with respect to quality of deposit and ease of arc manipulation or operator appeal.

Figure 5 shows the appearance of a typical joint made with stranded aluminum bronze using argon as the shield gas.

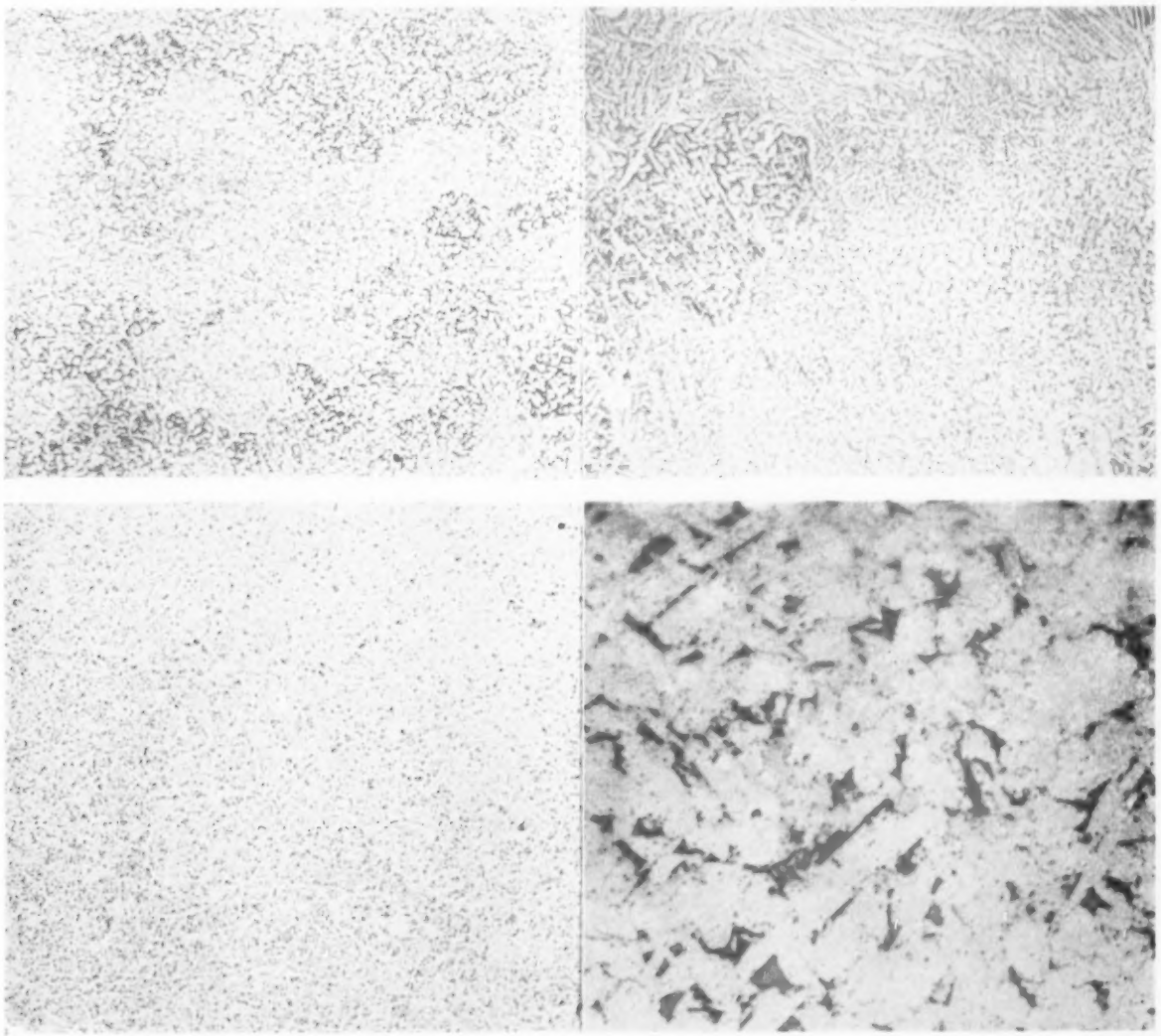
Technique plays an important role in the use of these electrode materials in order to achieve optimum results. Back-hand technique produces a deposit having a more convex contour with the least amount of penetration into the base material. The forehand technique produces welds having greater penetration with cleaner bead appearance and less convexity. With this in mind, back-hand techniques are always employed in root passes to reduce restraint cracking tendencies and to minimize dilution in overlay work. Forehand technique is primarily used for cover passes to present a more uniform appearance with minimum reinforcement.

Figure 6 shows cross sections of joints made in mild

* "A Comparison of Shielding Mixtures for Gas Shielded Arc Welding" was presented at the Oct. 1952 AWS Meeting. To be published in a later issue of THE WELDING JOURNAL.

Solid A100 electrode deposited on mild steel 100 ×

Stranded A101 electrode deposited on Grade 8 aluminum-bronze plate 100 ×

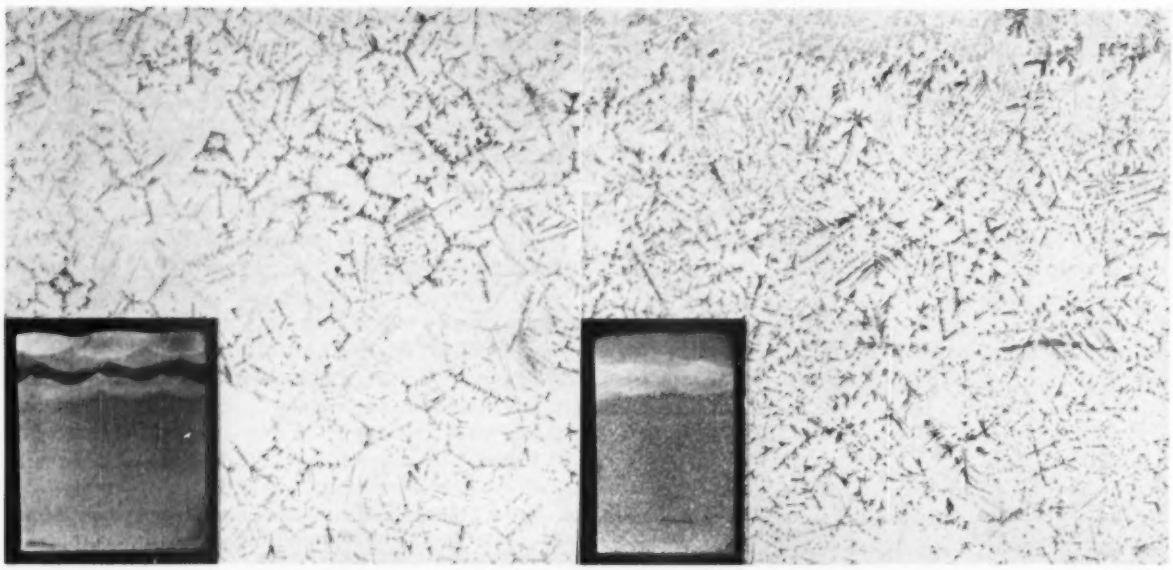


100 ×

1000 ×

Stranded A101 on mild steel

Fig. 7 Microstructures of aluminum-bronze (9% Al–1% Fe, remainder Cu) Aircomatic deposits

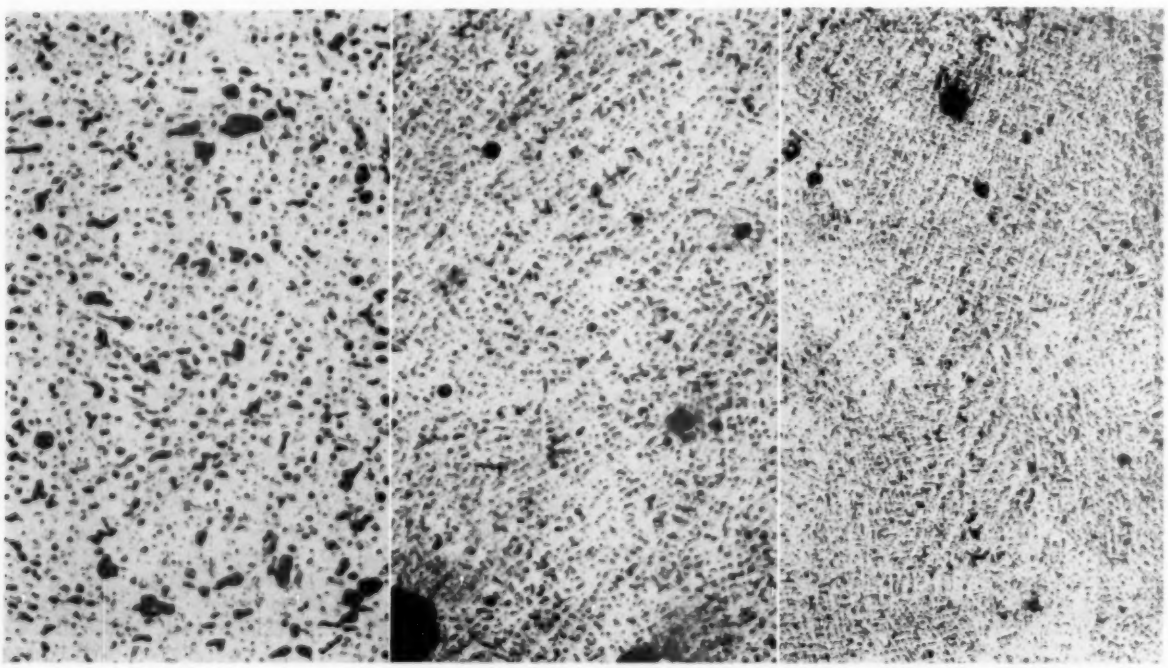


1 × 100 × 1 × 100 ×

A190 Stranded Aircomatic electrode (14% Al, 3% Fe, remainder Cu)
A161 Stranded Aircomatic electrode (11.5% Al, 3% Fe, remainder Cu)

Fig. 8 Structures of typical aluminum-bronze overlay deposits on $^3/_4$-in. mild steel plate

steel with A101 electrode using both stringer bead and weaving techniques. The structure of the stringer bead specimen has a homogeneous fine-grained appearance while the other contains areas of large columnar grain structure. It is therefore most usual to use the stringer bead technique where it is desired to minimize base metal dilution and to obtain a deposit of finer grained structure. Deposition analyses from the center of these joints reveal increased iron and decreased aluminum content in the joint made by weaving. The iron increase is due to increased base metal dilution, while the aluminum deficiency is caused by increased oxidation as a result of the larger molten pool present with this technique. Particular attention must be paid to the effects of technique in the welding of manganese bronze since the amount of zinc carryover from the base plate has a decided adverse effect on the ductility of the resulting aluminum bronze deposit.



Cast Bare electrode Aircomatic stranded A170

Fig. 9 Leaded bronze deposits—100×

DEPOSIT PROPERTIES

The structures of the aluminum bronze alloys are well known. Therefore, it will suffice to say that Figs. 7 and 8 show typical aluminum bronze electrode weld deposit structures containing 9–10% aluminum. Those in Fig. 7 which show the 9% aluminum–1% iron alloys, exhibit typical alpha phase with residual beta phase structure. The deposit on aluminum bronze plate exhibits the greatest area of beta due to the pick up of aluminum during welding.

The deposits in Fig. 8 were made with electrodes of increasingly higher aluminum content. It is believed the star-shaped structure is that of $FeAl_3$. The matrix is composed of alpha phase plus eutectoid for the A161 deposit and gamma phase plus eutectoid for the A190 deposit.

The important point to be gained from these pictures is the uniform appearance of the deposit structures indicating complete mixing of the separate constituents in the composite electrode as it passes through the arc and is solidified. Microhardness traverses do not detect hardness variations greater than are normally expected in aluminum bronze deposits. In particular it should be noted in these sections that there is no evidence of porosity or slag entrapment which would otherwise mar the quality of the deposits.

Figure 9 is a comparison of the microstructures of the original cast, lead-tin bearing and those from deposits made with a bare, cast electrode and with the composite leaded bronze electrode (A170) using the inert-gas consumable electrode welding process.

Again the mixing has been complete and the resultant alloy is uniform resembling both the bare electrode deposit and the cast alloy. The prime difference is the denser structure and reduced size of the dispersed lead particles with the Aircomatic process. The major advantages in this case are in the ease of operation, the lack of gross porosity and the increased deposition efficiency. Whereas the total deposition efficiency is about 50%, with the bare stick electrode, the Aircomatic electrode using argon shield gas is deposited at an efficiency of over 90% at a deposition rate of 10 lb per hour. This results in a saving of material as well as a superior deposit.

Table 3 compiles the properties of the weld deposits made with solid and stranded aluminum bronze electrodes of the 9% aluminum–1% iron type. The stranded electrode has purposely been constructed to have a lower aluminum content than that of commercially available solid wire. It was done to improve the ductility of the deposits still keeping the strength well above the minimum requirements. This is permissible in view of the improved efficiency of elemental transfer through the inert arc. These data prove that the stranded deposits are, in all cases, consistent with the results obtained with solid wire. The greater ductility is due to the lower aluminum content of the stranded composite. The improvement in the case of manganese bronze appears greater than might be expected and has been attributed to the less penetrating action of the arc using stranded electrode at equivalent current density. This has resulted in lower zinc content in the deposits made with stranded electrode.

Table 3—All-Weld-Metal Properties of Deposits Made with Solid Vs. Stranded Aluminum-Bronze Electrodes

	Stranded	*Solid*
Wire composition:		
Cu	90.0	88.8
Al	9.1	10.0
Fe	0.9	1.0
On Grade 8 Al-bronze plate:		
UTS, psi	77,800	82,000
Yield strength, 0.2%, psi	31,800	27,700
Elongation in 2 in.	34.0	27.5
BHN	101	114
On mild steel:		
UTS, psi	94,500	101,000
Yield strength, 0.2%, psi	38,600	40,300
Elongation 2 in.	28.0	27
BHN	130	160
On manganese bronze:		
UTS, psi	73,500	98,250
Yield strength, 0.2%, psi	27,500	36,750
Elongation 2 in	33	17
BHN	112	165

The results of mechanical tests on joints made with stranded and solid aluminum bronze electrodes of the structural variety on various base materials are given in Table 4. Here again the properties are comparable. The increased elongation in the cases of solid electrode deposits on aluminum bronze plate are due to increased elongation in the base metal outside the weld. This is a result of a closer match of weld and base metal strength. These specimens were tested without reinforcement so that in many structural applications the increased strength with the reinforcement will permit the stranded deposits to match the strength of annealed Grade 8 plate. The properties for joints made with A101 elec-

Table 4—Properties of Butt Joints Made with Solid Vs. Stranded Aluminum-Bronze Electrodes

	Stranded	*Solid*
Wire composition:		
Cu	90.0	88.8
Al	9.1	10.0
Fe	0.9	1.0
On 1/4-in. Grade 8 Al-bronze plate:		
Transverse tensile		
UTS-psi	71,300	79,100
Elongation 2 in.	23.0	34
Bend:		
Face	180 deg, 22%	180 deg, 22%
Root	180 deg, 36%	180 deg, 25%
On 1/2 Grade 8-Al-bronze plate:		
Transverse tensile		
UTS-psi	72,500	75,200*
Elongation 2 in.	28.5	18.5
Bend:		
Face	180 deg, 22%	180 deg, 16%
Root	180 deg, 20%	180 deg, 18%
On 3/8-in. mild steel plate:†		
Transverse tensile		
UTS-psi	68,000*	68,000*
Weld metal elongation 0.4 in.	7.5%	6.0%
Bend:		
Face	180 deg, 17.5%	180 deg, 15%
Root	180 deg, 12.5%	180 deg, 12.5%

* Failure occurred in plate.
† In accordance with ASTM B225-52T.

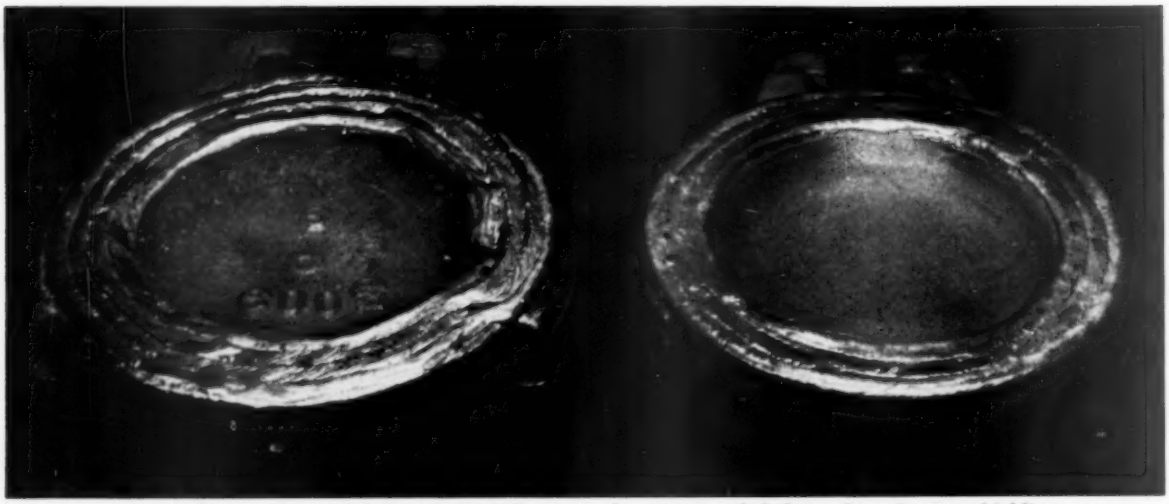


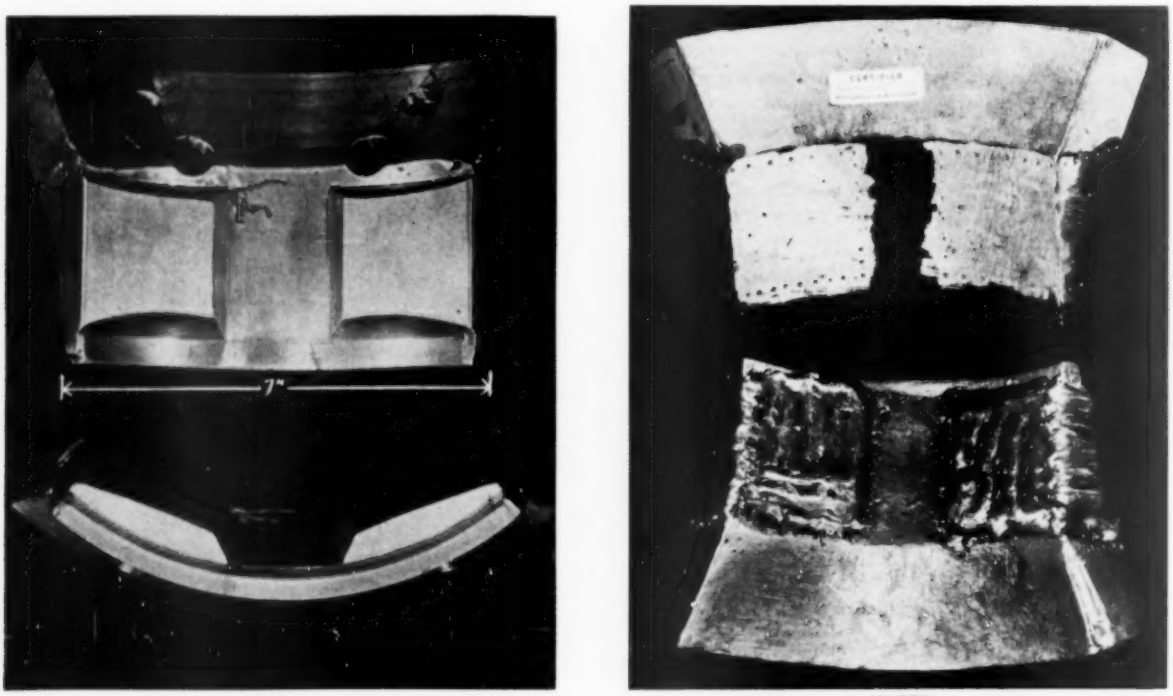
Fig. 10 Valve gates surfaced with A161 aluminum bronze stranded electrode and argon shielding

trode easily comply with the requirements of B225–52T which specify minimum tensile strength of 60,000 psi and 180 deg bends in $^3/_8$-in. mild steel plate welded with this alloy.

The strength of deposits made with the stranded aluminum bronze electrodes of higher aluminum content increase as the aluminum content is increased up to a peak value at about the eutectoid composition. The hardness is also increased but the ductility is lowered. The electrode corresponding to this peak value has been designated as A161. Deposits made with this electrode on mild steel have the following properties: 110,000 psi ultimate tensile strength, 53,000 psi tensile yield strength, 10% elongation in 2 in., and a hardness of 205 BHN.

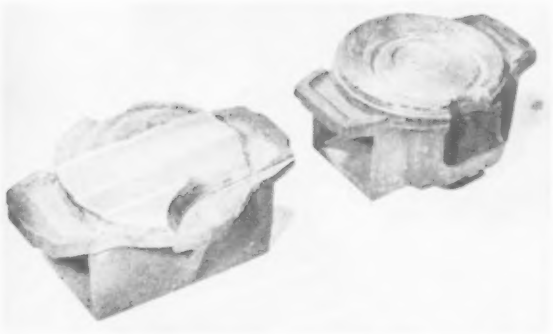
Further increasing the aluminum content in these electrodes results in still further hardness increases, but the strength is decreased with further lowering of ductility. Typical properties of A190 deposits on steel are: 58,000 psi ultimate tensile strength, 1% elongation with hardness values of 310 BHN.

From the previous data it is seen that deposits produced with the A101 electrode have properties which make it extremely useful as a structural welding material for joining steel, copper, nickel, aluminum bronze, manganese bronze, many other copper and



A190 320 BHN

Fig. 11 Aluminum bronze overlay pads on copper scarfing tip shoes



Aircomatic A170 stranded wire

Bare electrode

Fig. 12 Leaded-bronze build-up of locomotive thrust bearings

nickel base alloys and any one of these to another. The joint strength developed in steel is equivalent to that developed by some of the mild steel electrodes. The deposits of A101 electrodes also provide very good bearing surfaces when used to overlay steel parts which are subject to sliding friction. The corrosion resistance of deposits of this aluminum bronze make it useful in the fabrication of aluminum bronze vessels for the chemical industry.

The A161 bronze also finds application as a structural material. The higher strength of the deposits put it in the range of ultimate joint strengths equivalent to some alloy steels. The ductility is not as good, however. A161 electrode finds greatest application as an overlay material supplying an excellent hard, wear-resistant surface for steel and copper based parts.

The A190 deposits, with their high hardness and good bearing qualities, make them desirable as a forming die facing overlay material and for other applications where the part is to be subjected to extreme amounts of sliding friction.

FIELD APPLICATIONS

The stranded electrode for the Aircomatic process is a comparatively new development. The number of field applications on which there is adequate data is, therefore, limited.

Figure 10 shows the application of electrode A161 to steel valve gates. This alloy deposit is used because of its seating and corrosion-resistant properties. The stringer bead deposits were made at 275–280 amp and 27 v, with a shielding gas flow of 40 cfh of argon. The casting was preheated to 250 F and an interpass temperature of 400 F maintained.

Figure 11 shows the shoes of a large automatic scarfing machine. The bearing surfaces of these shoes rest on the hot bloom and accurately space the scarfing tips. The shoes are water-cooled, high conductivity copper. The bearing faces are surfaced with A190 aluminum bronze which gives excellent wearing properties and does not weld to the bloom surface. The first layer was put on at 300–325 amp with a preheat of 600 F. Subsequent passes were made at 260 amps. with an interpass temperature of 350 F. A gas flow of 40 cfh of argon was used. A surface hardness of 320 BHN was attained. Note the excellent quality of the machined deposit.

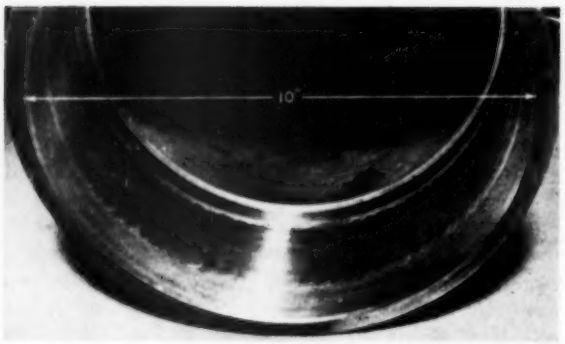
Figure 12 is a photo of diesel locomotive end thrust bearings. The housing is cast steel and a lead-tin bronze bearing is normally cast in a dove-tail recess to hold the bearing material to the steel. The dove-tail is a source of trouble as bearings come loose from pounding and pressure. Welding was proposed as a solution to this problem. The bearing which was built up with the cast, bare electrode is quite porous. The metal transfer is very poor, and much of the electrode is lost in spatter. The deposit made with the Aircomatic process and stranded electrode is smooth and relatively free of porosity. An intermediate layer of deoxidized copper is deposited directly on the steel surface.

The National Rubber Machinery Co., of Clifton, N. J., has more than tripled production of aluminum bronze overlays on piston recoil sleeves for the 90-mm gun in T48 Military Tanks through the use of stranded A101 aluminum bronze electrodes and the Aircomatic process. Figure 13 pictures the welding being done on the 10-in. ID SAE 4130 steel cylinder mounted on a motorized positioner. The overlay is deposited in two passes by weaving the manual gun in and out as the cylinder is slowly rotated beneath it. Figure 14 (*a*) shows the completed beads as welded. Figure 14 (*b*) shows the overlay as machined and ready for subsequent heat treatment of the cylinder. The resultant deposit is clean, sound and of uniform hardness. In addition to the increased speed and improved quality only 2 ½ lb of Aircomatic electrode wire are required in contrast of 6 lb of coated electrode previously used for each sleeve.

For the fabrication of cast-welded aluminum bronze rudders for mine sweepers, the Backus Machine Co., Carlstadt, N. J., have been using solid aluminum bronze electrode in conjunction with the Aircomatic process. They have recently completed tests for the conversion from solid to stranded electrode for this application.

Fig. 13 A101 stranded electrode being applied to a low alloy steel cylinder

(a) As welded



(b) As machined

Fig. 14 4101 aluminum bronze overlays on low alloy steel cylinders

Each rudder is composed of a basic cast structure—the rudder stock—to which the following elements are welded: a canoe or bottom edge, a top edge blade, five ribs and a skin section covering the ribs. Figure 15 shows the structure near completion. A variety of weld types are utilized in this application. These include horizontal fillet and butt welds, plug welds and vertical fillet welds. This is a demonstration of the adaptability of stranded electrode materials to some types of position welding.

The experimental work in several shipyards on the use of stranded aluminum bronze electrodes for manganese bronze propeller casting repair is proceeding with such excellent results that we expect to see this process become standard procedure for this application. As previously pointed out, the softer arc of the stranded electrode reduced penetration and zinc dilution, resulting in improved properties. This softer arc is also desirable for overlay applications.

SUMMARY

1. It has been shown that several alloys which cannot be drawn into continuous lengths of wire for Aircomatic application can be supplied in composite form. At the present time, several aluminum bronze compositions and a high lead-tin bearing alloy are offered commercially.

Fig. 15 Fabrication of aluminum bronze marine rudder

2. A compositing method is used which strands several pure metal wires together in the proper proportion for the desired alloy. This results in excellent chemical control, extremely low impurity and consistent chemical analysis throughout the electrode length and from spool to spool.

3. Tests show that the wire elements of the strand thoroughly mix and alloy together in the arc and deposit. The properties of the deposit compare favorably with that obtained from solid alloy wires. At the same current densities the stranded electrode produces a softer arc than the solid wire. This is advantageous for overlay work on steel and for joining manganese bronze or brass where high base metal dilution is undesirable.

4. Several successful field applications demonstrate that the stranded electrode wire for difficult-to-draw alloys is commercially feasible. Compositing has now made alloys available for consumable electrode, inert gas welding and over-laying which were not hitherto available. The application of these alloys can be expected to increase.

ACKNOWLEDGMENT

The authors are pleased to acknowledge the assistance of Howard Stirn, Research Engineer with J. A. Roebling's Sons Co., who translated the requirements for stranded electrodes into the finished product and the Process Development Department of the Air Reduction Sales Co. for their assistance in gathering the application data.

Fillerarc Welding Process

Some of the developments and experimentation that were necessary to put on the market new equipment for consumable electrode gas-shielded welding

by R. W. Tuthill

FILLERARC is the name of General Electric Co.'s new equipment designed for consumable electrode gas-shielded welding. It consists of three main components—a gun, a wire drive unit and a uniquely designed welding generator—working together as a team to overcome difficulties encountered in the application of other similar equipments.

The high-speed, high-current density gas-shielded process is only a few years old. Applications thus far have been hampered by the necessity of using existing welding generators not specifically designed for this radically different welding process. As a result the applications require long set up time, are extremely critical in adjustment, and require great skill on the part of the operator.

Our philosophy used in the design of the Fillerarc equipment was to abandon the habitual approach of using existing equipment and first study the basic fundamentals of this new welding process. A proper evaluation of the arc characteristics then made it possible to design the best apparatus for the process.

It was felt that the range of applications of this new process could be greatly increased by the use of smaller diameter wire in order to keep the welding current low and still maintain the high-current density so necessary for proper arcing. Therefore, it was our decision to design a gun and wire drive unit that would easily feed wire by pulling it into the gun, then pushing it only a few inches. Our experience has been that the Fillerarc gun and wire drive unit will even feed 0.030-in. diam aluminum wire without the full hard requirement, and there are indications that we will be able to feed wire of even smaller diameter.

Our next problem was the development of a welding power source that would be easy to control and meet the peculiar requirements required by this process. It was earlier determined that the use of a conventional type welding generator was not the answer. This is not surprising since the gas-shielded welding process is so different from standard metal-arc welding techniques that new problems must be expected. In welding with flux-coated electrodes, the desirable arc voltage and length are usually fixed for any set of conditions. The operator controls the current output by adjusting the welder to operate on an output curve to get the desired current. All such welding generators have current calibrations made to correspond with the arc voltage most usually encountered.

In consumable electrode gas-shielded arc welding, the current density on the electrode is several times greater than that used in welding with flux-coated electrodes. This high-current density is necessary to produce satisfactory welds with this process. Because the electrodes are operated at such a high-current density, feeding speeds of several hundred inches a minute are commonly used. Burn-off rate of the wire (consumption in inches per minute) must equal feeding speed for stable welding conditions. If the feeding speed is slower than the consumption the arc will get longer; and if the feeding speed is more than the consumption, the arc will get shorter and finally short-circuit. The burn-off rate is almost directly proportional to current and is not very much affected by changes in arc voltage. It is very important to understand that in this type of welding, since wire feeding speed is preset beforehand, the current requirement of the arc is already established before welding.

The other variable to be controlled is arc length, and this is set by the operator before welding by adjustment of the welder. This is different from flux-coated electrodes in which the setting on the welder adjusts current and the arc length is adjusted by the operator as he welds.

Now if the current requirements of this new welding process are fixed before the operator starts to weld, he cannot possibly control current by adjustment of the welder! The only thing the operator can do by adjusting the welder using this process is to select the output curve of the welder which will produce the current at the correct arc length within the requirements of the preset wire-feeding speed. He may think he is adjusting current on the welder, but in reality he is only adjusting arc length!

R. W. Tuthill is connected with the General Electric Co., Fitchburg, Mass.

Presented at the National Spring Meeting, AWS, Houston, Tex., June 16-19, 1953.

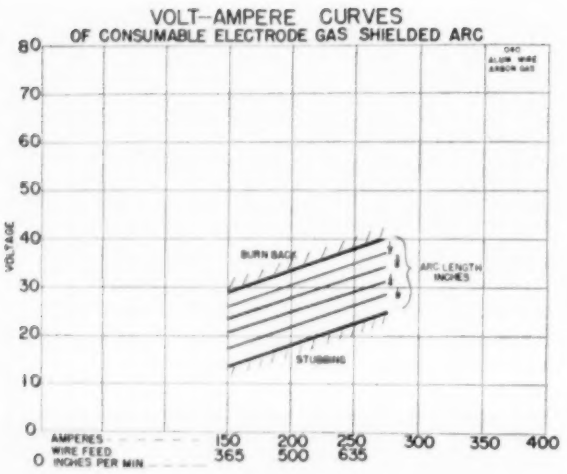


Figure 1

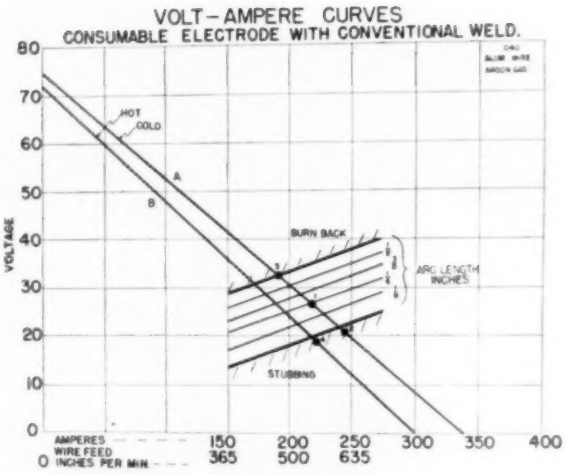


Figure 2

The welding generator does not know what current will be required of it until the arc is started and then it may not be able to supply the necessary current at the proper arc length (arc voltage) since the output curves reach zero voltage at relatively low currents on conventional generators. Also most welding generators have current calibrations, and we have seen it is not possible to adjust the current in this process by adjusting the controls on the welder. The wire-feeding speed used establishes the current requirements beforehand. These are the reasons why a conventional welding generator is not suitable for this type of welding process.

In order to design a generator to supply this consumable electrode gas-shielded arc, a study was made of the arc characteristics themselves. Curves of arc voltage, arc length and welding current were made for many different types of wire and gas used in this process. One such set of curves will serve to illustrate the arc characteristics. Figure 1 shows the curves for 0.040-in. diam aluminum wire in argon gas; arc current plotted against voltage for different arc lengths. These curves show that as the current increases the arc voltage also increases if the arc length is maintained constant. It must be thoroughly understood that this is a characteristic of the arc and is not affected in any way by the source of welding power.

The abscissa of the curves is also marked in wire-feeding speed. A burn-off rate (feeding speed) of 500 ipm requires a current of 200 amp ($\pm 5\%$), regardless of whether welding is taking place with a long arc or a short arc.

In order to understand the action of this consumable electrode gas-shielded process, it is necessary to lay the groundwork for the parameters utilized. This process is already somewhat self-regulating; that is, the arc length need not be electronically controlled but can be mechanically regulated by the welding arc.

The difficulties of adapting a conventional direct-current welder to these arc characteristics are well recognized, but a summary of the problems may be seen by referring to Fig. 2. This shows the familiar drooping volt-ampere characteristic superposed on the curves from Fig. 1. After the operator has adjusted the welder and wire feed properly, he may weld successfully on Curve *A* at Point *1* with a $^1/_4$-in. arc length at about 215 amp (a wire-feeding speed of 550 ipm) and an arc voltage of about 26 v.

The mechanically self-regulating action of the arc is explained as follows: If the arc current is exactly the amount needed to consume the wire at the rate it is being fed into the arc, then the conditions are stable; the arc current, arc voltage and arc length will not change. If, then, the wire feed is increased slightly, it will be feeding at a higher rate than it is being consumed; welding conditions will then proceed down Curve *A* until the required higher current is reached. It does this automatically, to stabilize at a higher current, lower voltage, and shorter arc length, this new current being that required to consume the wire at the increased feeding rate.

If, however, the increase in wire feed was sufficient, welding conditions may now be in the area (Point *2*) marked "stubbing." This is the area of frequent short circuits, spatter and unsatisfactory welding. The allowable range of operation is very narrow and requires meticulous adjustment of the welder.

Starting at Point *1* again, the opposite regulating action is apparent if the wire feed is decreased. Then the arc is consuming the wire at a faster rate than it is being fed and the welding will proceed up Curve *A* until the required lower current is reached.

If, however, the decrease in wire feed was enough, welding may take place in the area (Point *3*) of long arcs marked "burn-back." As can be seen, this is also a very narrow range of adjustment. Whenever the arc is operated in the area of "burn-back" condition, the arc length becomes so long in this type of welding that the arc stretches back and touches the last metallic part of the operator's gun and the arc then operates from this point and fuses to the gun, damaging it. This is called

a "burn-back" and may cause a shutdown to replace the damaged parts.

It requires considerable operator skill to adjust the generator and wire-drive unit to find the proper welding conditions. This is difficult, because the adjustment of welding current (wire-feeding speed) also affects the arc length.

Many things may change the position of the output curve of the welder. Curve *B* of Fig. 2 is typical of a motor-generator welder as it changes from cold to hot. Since the output curves shown are at the arc, changes in heating of welding leads or poor grounds can also shift from Curve *A* to Curve *B*. Starting at Point *1* on Curve *A*, a shift to Curve *B* will cause welding to take place in the area of stubbing so that the operator must readjust the welder to produce Curve *A* once more.

A rectifier-type welder of conventional design, although usually not subject to as much heating load dropoff as a motor generator set, does have its output curve shifted as a result of line voltage fluctuations. It makes no difference what changes the output curve, the arc welding result is the same. If, because of kinks in the wire or broken wire, the feeding speed is drastically reduced or stops altogether, burn-back almost surely will occur.

Burn-back may occur at the end of the weld as the wire feed stops. Welding conditions follow the output curves up into the burn-back area. It becomes necessary to synchronize auxiliary controls to operate contactors at the beginning and end of the weld so that the arc current is controlled and not allowed to burn back. This necessitates elaborate scratching techniques upon starting to establish the arc without sticking for some metals and requires a pecking technique to be used with others.

In the course of welding, an operator usually has to vary the current to make accommodations for fit-up, position of the joint or variations in the thickness of the metal to be welded. The operator can change wire-feeding speed and hence current requirements only over a very narrow range with a conventional welder. What is also important is that when current is changed over this range by changing wire feed, then the arc length may be incorrect requiring a readjustment of the welder. This means that the operator must juggle machine adjustment and wire speed every time he wishes to change current. Repetitive setups are not always possible with the same machine settings because of changes in heating, line voltage, cable resistance and other factors. Welding thus with the conventional machines designed to be used with flux-coated electrodes could hardly be called satisfactory.

Welding tests were made with a generator with a flat volt-ampere characteristic. This was a step in the right direction, but refinements of this type of machine are very desirable. A generator of this type would be similar to older constant potential welders but with lower open-circuit voltage. The output curve for such a machine is shown in Fig. 3. Welding on the curve shown will produce better results than with a conventional motor generator welder. Wider variations in wire-feeding speed may be tolerated without stubbing or burning back. However, as the operator changes wire-feeding speed to produce the correct current for the joint requirements, he will find it necessary to readjust the welder in order to operate with the same arc lengths which he needs for proper gas coverage and weld puddle control. When operating under conditions requiring long arcs or high currents, burn-back difficulties can be encountered. This can occur as before when the wire feed is stopped, unless separate line contactors are synchronized with feeding controls to separately disconnect welding power before the wire has stopped feeding.

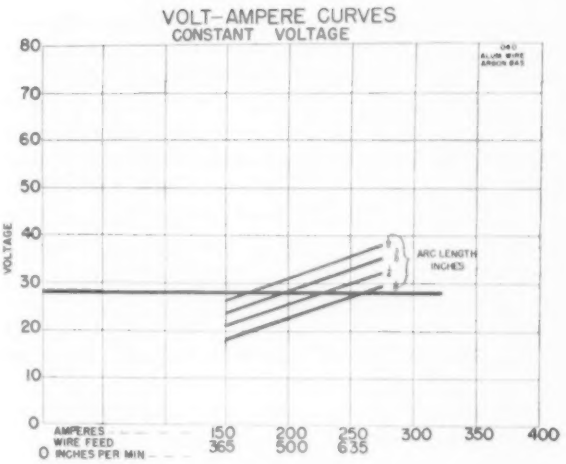


Figure 3

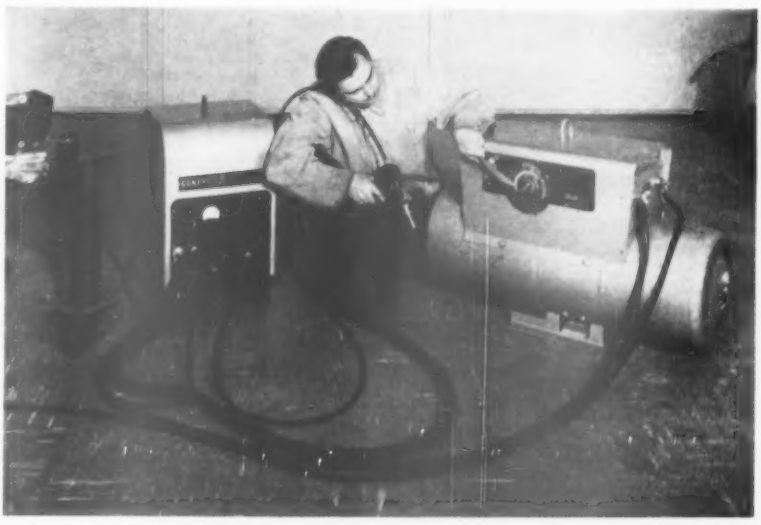


Figure 4

For these reasons a new General Electric Fillerarc motor generator type welder has been developed based on a completely new concept of welding with this process. The picture in Fig. 4 shows the Fillerarc welder connected to the wire-drive unit and gun ready for welding. It has a very low open-circuit voltage—between 10 and 30 v with a rising characteristic, i.e., as current is produced by the welder, the voltage generated increases. This is entirely different from any other welding generator ever made for this type of welding and now makes this process completely self-regulating.

This new welding process is so different from older methods of welding that it makes it necessary to change our whole concept of current control.

The Fillerarc welder is designed to give constant arc length and will produce any current required up to its full rating on any setting; therefore, it is prepared for any wire-feeding speed and will supply the current necessary to melt off the wire at exactly the rate it is being fed. The settings on this machine are for arc length only and no current calibrations appear on the dial.

Thus we see that in this new process the significance of arc current and arc voltage disappear and instead the wire-feeding speed and arc length are the only variables to be controlled.

To see how this works, refer to Fig. 5. Here we see about a $^5/_{16}$-in. arc length characteristic in which the wire feed may be adjusted over a very wide range to produce the necessary heat in the arc without changing arc length. This gives the operator great flexibility by permitting him to change wire feed even while welding without the necessity of readjusting the welder to maintain the same arc length. The welder maintains the correct constant arc length automatically.

The simple controls on this new machine are used to adjust the welder to match the slope and position of the required arc length characteristic curve. Referring to Fig. 5, the machine may be adjusted to change from the curve for $^5/_{16}$-in. to any other arc length. Wire diameter and material and shielding gases will change the slope and position requirements.

Another important feature of this new welding generator is that the effect of generator heating is very small and output curves change very little from cold to hot. This means that settings of arc length will remain constant.

The problem of burn-back has been mentioned. This is probably one of the largest obstacles to immediate application by unskilled personnel with this process. It is very irritating, costly and unusually wasteful of time and equipment and considerable skill is required to prevent this burn-back while welding. Since this Fillerarc welder has very low open-circuit voltage, it is very unlikely to cause burn-back while welding. The operator merely positions the gun, pulls the trigger to get preliminary gas coverage, releases the trigger to feed wire and the arc is automatically started as the wire touches the work. When the operator wishes to stop welding, he pulls the trigger, causing the wire to stop feeding. He leaves the gun in place over the weld providing gas coverage as the weld cools. As the wire stops feeding, the arc current is reduced to zero, the generator voltage drops and the arc goes out without burning back to the gun. This permits the operator to provide the proper gas coverage at the end of the weld and to get somewhat of a crater filling action. This crater filling action is a result of the reduced current that flows as the wire stops feeding. It also enables the operator to make continuous tack welds without raising the face shield, cutting off the wire or making awkward starting and stopping motions.

The starting sequence in the Fillerarc welder is to press and release the trigger; as the wire strikes the work, the arc starts smoothly as a result of the carefully designed transient starting characteristics.

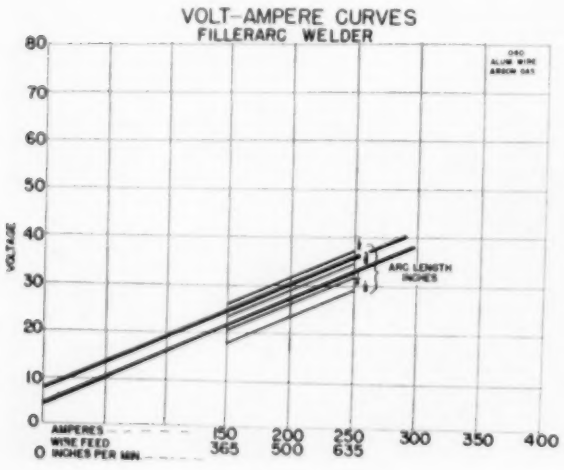


Figure 5

Figure 6

The wire drive unit and the gun for this Fillerare process also have some unusual features. (See Fig. 6.) They differ from other similar equipment in that the wire is propelled by feed rolls in the gun itself which pull the wire from the reel on the wire-drive unit and push the wire only 6 in. This is a fundamental change, and makes it possible to weld with very small diameter wire. The wire-drive unit contains a Thy-mo-trol motor control and also houses a reel of wire. Thy-mo-trol is the registered trademark of General Electric Co. for an electronically controlled electric motor. It provides for this new welding equipment a source of wire-feeding speed that is constantly, accurately controlled and easily adjusted to narrow limits. A voltmeter is provided to give the operator instantaneous indication of wire-feeding speed. He does this by feeding the wire and reading a voltmeter which is calibrated directly in inches per minute of wire feed. This eliminates the time-consuming necessity of feeding the wire for a preset period and then measuring it and calculating the wire feed in inches per minute.

The flexible shaft connected to the wire-drive unit motor turns a small set of knurled feed rolls located in the gun. These knurled rolls pull the wire from the reel on the wire-drive unit through nylon tubes and bushings to the contact tip in the gun so that the only metallic parts touching the electrode wire are the knurled feed rolls and the contact tip at the gas nozzle where current is supplied to the wire. The whole apparatus is water-cooled and capable of carrying currents of 400 amp continuously. One set of knurled drive rolls in the gun have a capacity of wire from 0.030 in. diameter to 0.065 in., inclusive, with any size and any type of wire being used and only a slight screw-driver adjustment is necessary to accommodate this wide range. A set of feed rolls for larger wire is available, which will handle from 0.060- to 0.093-in. diam wire. A change from steel to aluminum or from one size wire to another is easily accomplished in the matter of a few minutes with few additional parts using the same gun.

The wire-drive unit in addition to a Thy-mo-trol motor control contains a gas solenoid valve, control relays and a spindle for the electrode wire. The apparatus is dynamically braked so that at the end of the weld the wire projecting from the nozzle of the gun is the correct length for the next start and does not need to be trimmed with pliers. The reel of filler wire also has a solenoid brake energized whenever welding is not in process; this prevents over-running of the reel and entangling the wire. The maximum wire-feeding speed obtainable by this apparatus is 750 ipm with a two-speed range switch. This speed can be increased, if necessary, by a slight change in internal resistors.

A voltmeter and a two-position switch, mounted on the panel, serve two functions. In one position, it permits the operator to read the open-circuit voltage of the welder. In the other position, the voltmeter reads wire speed in inches per minute, as mentioned above.

This General Electric Fillerare equipment will greatly enlarge the application of the gas-shielded welding process by simplifying control, decreasing operator training time, operating and maintenance costs.

CURRENT WELDING LITERATURE

Aircraft, Fuel Tanks. World's Largest Wing Tanks, W. P. Brotherton. Aero Digest, vol. 65, no. 6 (Dec. 1952), pp. 90, 92, 94, 96–99.

Aircraft Manufacture. Resistance Welding of Aircraft Structures, J. Starr. Aero Digest, vol. 65, no. 6 (Dec. 1952), pp. 50, 52, 54, 56, 58.

Chemical Equipment. Use of Stainless Steel in Chemical Industry, W. B. Clarke. Australasian Engr., vol. 45 (Jan. 1953), pp. 59–65.

Coke Handling. Welded Aluminium Coke Skips. Gas J., vol. 273, no. 4682 (Feb. 25, 1953), pp. 447–448.

Diesel Engine Manufacture. Production of Diesel Engine Weldments. Can. Transportation (Oct. 1952), pp. 539–541.

Joints. Determination of Stresses in Cemented Lap Joints, R. W. Cornell. Am. Soc. Mech. Engrs.—Paper No. 53—APM-15 for meeting June 18–20, 1953, 10 pp.

Light Metals. Aireomatic Welding Demonstration. Shipbldg. & Shipg. Rec., vol. 81, no. 16 (Apr. 16, 1953), p. 510.

Marine Engines. Welding in Marine Engineering, H. N. Pemberton. Engineering, vol. 175, no. 4538 (Jan. 16, 1953), pp. 73–76; (illus.), p. 80; no. 4539 (Jan. 23), pp. 122–125; see also Engineer, vol. 195, no. 5061 (Jan. 23, 1953), pp. 131–133; no. 5062 (Jan. 30), pp. 160–162.

Marine Engines. Welding in Marine Engineering, H. N. Pemberton. Machy. Market, no. 2725 (Feb. 6, 1953), pp. 26–28; no. 2726 (Feb. 13), pp. 27–28, 30; no. 2727 (Feb. 20), pp. 24, 26; see also Brit. Motor Ship, vol. 33, no. 395 (Feb. 1953), pp. 484–485; Mar. Engr. & Naval Architect, vol. 76, no. 913 (Feb. 1953), pp. 47–50.

Metal Analysis, X-Ray. Economic Aspect of Radiographic Inspection, V. E. Pullin. Engineer, vol. 194, no. 5051 (Nov. 14, 1952), pp. 641–643.

Metallurgical Developments in 1952. Engineer, vol. 195, no. 5060 (Jan. 16, 1953), pp. 109–110.

Motor Bus Maintenance and Repair. Salvaging Isn't Job at CTS . . . It's Project Worth $228,788! Bus Transportation, vol. 32, no. 4 (Apr. 1953), pp. 31–33, 128.

Rails, Welding. Long Continuous Rail on T. H. and B. Can. Transportation (Nov. 1952), pp. 597–599.

Rails, Welding. Report of Special Committee on Continuous Welded Rail. Am. Ry. Eng. Assn.—Bul., vol. 54, no. 507 (Feb. 1953), pp. 1161–1173.

Trackless Trolleys, Maintenance and Repair. Metal Spray, Welding Rod Turn Old Parts Into Gold. Bus Transportation, vol. 32, no. 3 (Mar. 1953), pp. 30–31.

Welds, X-Ray Analysis. 150-kv. X-Ray Equipment for Radiography of Circumferential Welds in Gas-Turbine Rotors, F. W. Waterton. Inst. Elec. Engrs.—Proc., vol. 100, pt. 2 (Power Eng.), no. 74 (Apr. 1953), pp. 105–112; (discussion) 112–114; see also abstract in Engineering, vol. 174, no. 4533 (Dec. 12, 1952), pp. 774–775.

Wire, Cold Pressure Welding of Wire, E. D. Sickels. Wire & Wire Products, vol. 27, No. 12 (Dec. 1952), pp. 1298–1299, 1323–1324.

Plastics. Welding of Thermoplastics, F. L. Connors. Australasian Engr., vol. 45 (Mar. 1953), pp. 55–58.

Restoration of Ductility in Alloy Titanium Welds

Advance in welding technology points the way toward expanding the strength range of titanium grades available for welded parts

by A. J. Rosenberg, E. F. Hutchinson and S. Weiss

Abstract

Unique heat treatments have resulted in a marked increase in ductility of inert-arc welds in RC-130A, titanium alloy. An intensive program to determine the times and temperatures for heat treatment and welding conditions for optimum weld properties is discussed.

INTRODUCTION

A SERIOUS need has existed for a method of producing ductile welds in high-strength titanium alloys so that the full potential of these materials might be realized in industry. To date, it has been possible to develop only those fabricated parts which could utilize the lower-strength weldable grades.

During the past few years, variations in welding methods and novel techniques have been investigated in the hope of producing ductile welded joints in RC-130A and other high-strength titanium grades containing metallic alloy additions. Vendors, aircraft engine and air frame manufacturers, and research organizations throughout the country have been actively engaged in work directed toward the solution of this problem. Experiments in the Thomson Laboratory of the General Electric Co. have included ultrasonic vibration of welded joints during welding, water quenching immediately after welding, surface cleaning, filler material additions and various heat treatments. Until recently, all experiments have failed to produce an appreciable improvement.

The purpose of this investigation was to increase the ductility of inert-arc-welded joints in RC-130A to practical levels and to point the way toward further experimentation.

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FUNDAMENTAL CONCEPTS

RC-130A is a titanium-manganese alloy. A typical equilibrium diagram for this type of alloy is shown in Fig. 1.

Above 1616° F, material having a zero manganese content consists of a single-phase beta body centered cubic structure; as the temperature decreases below 1616° F the material transforms to a single-phase alpha hexagonal close packed structure. With increasing manganese content, the transformation temperature decreases until a point is reached where the transformation is suppressed until the beta phase becomes stable at room temperature. Between these two extremes, a two-phase region of alpha and beta exists.

At 8% manganese, the composition of RC-130A, the solid solution of beta transforms to an alpha-beta structure upon cooling under conditions approaching equilibrium. In welding, however, the cooling rates are so rapid that an all beta structure is retained at room temperature. This unstable structure is hard and brittle, so that it would be desirable to cause transformation to the stable alpha plus beta state after welding.

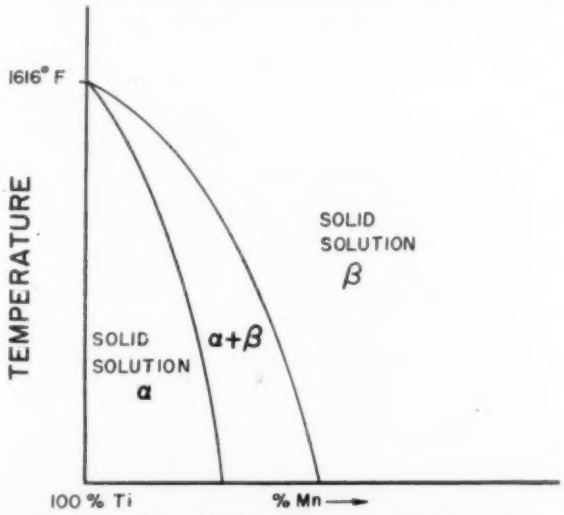


Fig. 1 Partial equilibrium diagram of Ti-Mn system

The condition is similar to that which exists in alloy steels when an undesirable structure forms upon cooling from welding temperatures.

With steels, metallurgists and welding engineers have utilized isothermal transformation diagrams to determine optimum pre- and postheating temperatures as a means of approaching equilibrium conditions. The successful welding of such material as SAE steels 4130 and 4340 could then be accomplished.

While many heat treatments had been applied to titanium alloy welds without success, isothermal treatments of the type used effectively with the above-mentioned steels seemed worthy of investigation.

A partial isothermal transformation diagram for RC-130A was obtained from W. L. Finlay, Research Manager of Rem-Cru Titanium, Inc., and a study was initiated on the effects of transformation on inert-arc-welded joint properties.

The curve made available by Rem-Cru Titanium, Inc., is reproduced in Fig. 2. Dr. Finlay has pointed out that this information was obtained on sketchy data from the original RC-130A product and therefore it cannot be considered highly accurate today. However, the curve did serve a useful purpose in our studies.

In welding, the molten weld area is far above the beta solvus temperature in Region 1. The drastic cooling rate, which follows welding retains the high-temperature beta phase in a hard and brittle condition at room temperature, shown as Region 2 in the figure. Heating above the solvus temperature, hot quenching to Region 3 and isothermally treating from Region 3 to Region 4 should transform the quenched beta of the weld to alpha plus beta. Slow, continuous cooling from Region 1 might also result in complete transformation provided that a suitable cooling rate could be established. It was hoped that a fully transformed weld structure would possess improved ductility over an all-beta structure but this fact was not known.

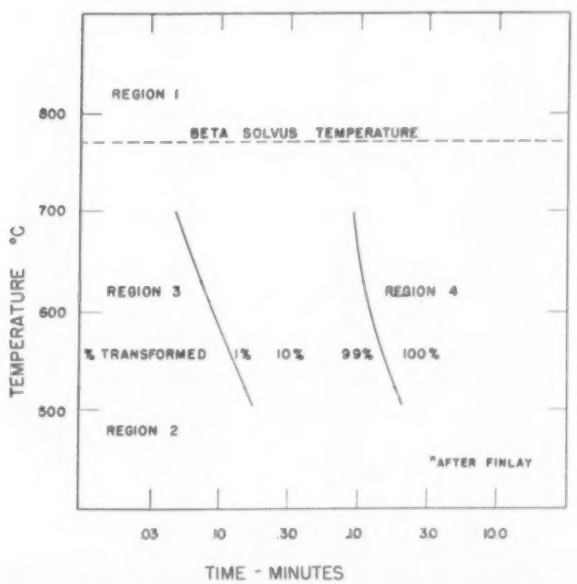


Fig. 2 Time-temperature transformation RC-130A (hot quenched from 30 min at 850° C)

The heat of RC-130A subjected to testing possessed room temperature tensile and yield (0.002 in./in.) strength levels of 126,000 and 108,000 psi, respectively, while tensile elongation in a 2-in. gage length was 19%. The alloy was capable of bending 180 deg in a longitudinal direction at a bend radius of $1^1/_2$ times the material thickness (0.090 in.).

EXPERIMENTAL PROCEDURE AND RESULTS

Inert-arc welded joints were prepared by semiautomatically welding along butt joints employing a special nozzle attachment to insure adequate surface protection and utilizing an inert gas for protection of the weld underside.* Although weld appearance was excellent, an as-welded joint failed brittlely at 73,500 psi and broke almost immediately in bending with little or no plastic deformation; it possessed a knoop hardness of 457 (Rockwell C, 46).

Samples from the same welded joint, placed in a stainless steel retort with titanium chips and a positive flow of 25 cfh of argon maintained, were subjected to the following heat treatment: 1560° F (850° C)—30 min; 1120° F (600° C)—10 min air cooled.

Three minutes elapsed in transferring the retort from one furnace to another. Temperatures were selected from Fig. 2 as those likely to result in transformation.

The titanium chips and argon atmosphere were introduced to prevent oxidation of the joint surface during treatment. While such oxidation might not be harmful, it was considered desirable to reduce any possible extraneous source of embrittlement.

The above heat treatment reduced weld hardness to a knoop value of 323 (Rockwell C, 32), increased tensile strength to 121,500 psi and permitted bending to nearly 90 deg at a radius of twice material thickness. However, tensile elongation was only 3%.

Microstudy of the as-welded and beta-tempered specimens revealed that transformation had taken place. Figure 3(*A*) depicts the coarse-grained, all-beta as-welded structure, while Fig. 3(*B*) shows a coarse-grained, alpha-plus-beta structure resulting from welding and heat treatment.

With these highly encouraging results and substantiation of theoretical considerations, efforts were turned toward the establishment of optimum times and temperatures for heat treatment in the hope of improving both the tensile and bend ductilities.

The heat treatment, in addition to improving the weld properties, also caused grain growth in the parent material to ASTM grain size greater than 1. Since it was felt that a fine-grained structure would be more ductile than a coarse-grained one, any means used to restrict grain growth in the parent material would be ad-

* Since all of the titanium alloys have a marked affinity for oxygen, hydrogen and nitrogen at temperatures above 1000° F, the materials must be protected from the effects of air during welding.

vantageous. Grain growth is a function of increasing temperature and/or time at temperature so that the minimum time and temperature necessary for complete transformation should result in the least detrimental grain growth in titanium.

One-inch-square samples of parent metal were heated at several temperatures above the beta solvus and quenched in water to retain the structure for microexamination. It was found that at temperatures between 1500–1530° F an all-beta structure was formed between 4 and 12 min, that grain growth occurred with increasing time, and that the smallest all beta grains were ASTM 2–3. At temperatures between 1480–1505° F, an all-beta structure of ASTM grain size 3–5 was observed after 4–4 $^1/_2$ min, while after 2 min traces of alpha were still present. With increasing time, grain growth continued, as shown in Fig. 4, so that 1500° F for 4–4 $^1/_2$ min were considered the most satisfactory conditions for initial treatments in the beta field.

In order to obtain samples for microstudy and to expand the transformation data furnished by Rem-Cru, parent metal specimens were held at 1500° F for 4 $^1/_2$ min, hot quenched in salt pots to a series of intermediate temperatures between 650 and 1000° F, and isothermally transformed for various times.

At temperatures of 650 and 745° F, no transformation occurred after 1800 sec. At 840° F significant

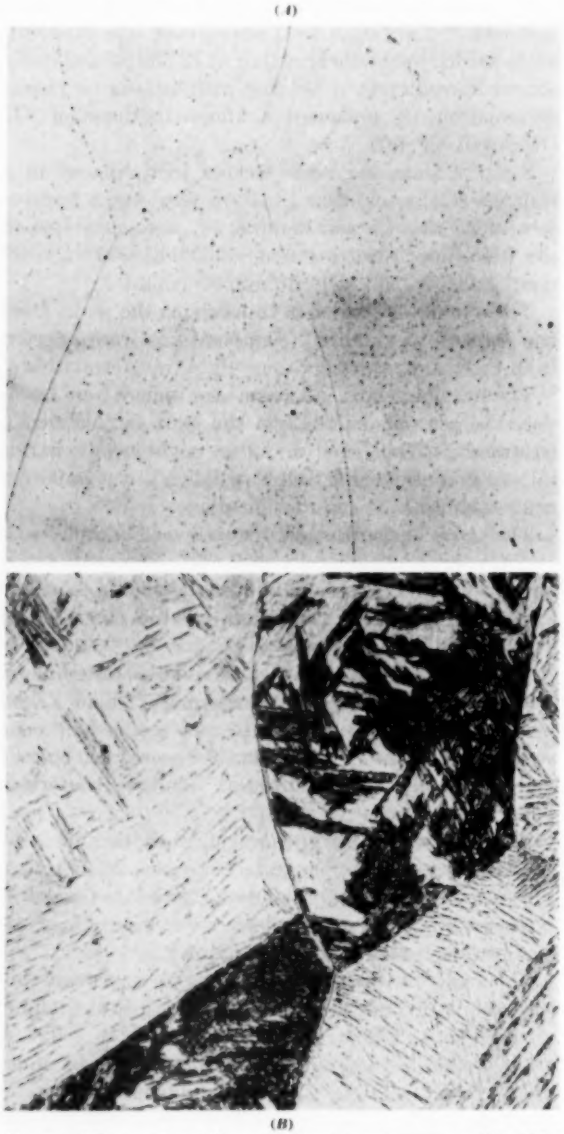


Fig. 3 Effects of welding and heat treatment on RC-130A

(*A*) As-welded structure. × 500. Note: Coarse all-beta grains. (*B*) Welded and heat-treated structure. × 500. Note: Grains now contain alpha plus beta.

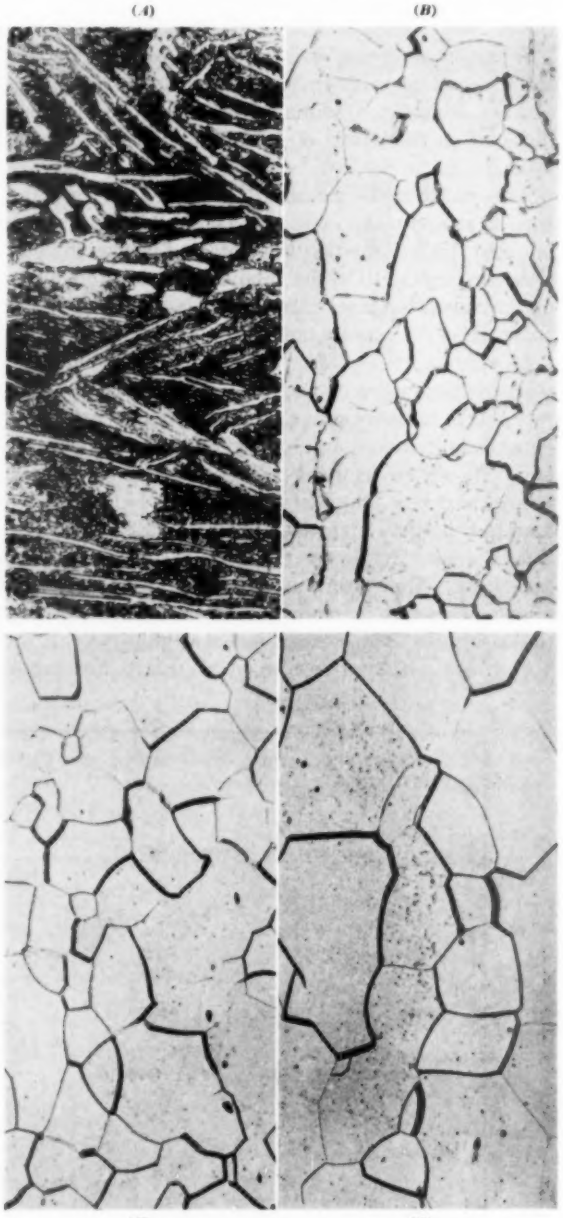


Fig. 4. Effects of time on beta grain size. × 500. (RC-130A water quenched from 1480 to 1505° F)

(*A*) As-received material. (*B*) 1500° F—2 min, water quenched (traces of alpha present). (*C*) 1500° F—4 to 4 $^1/_2$ min, water quenched ASTM grain size 3–5). (*D*) 1500° F—6 min, water quenched (ASTM grain size 2–3).

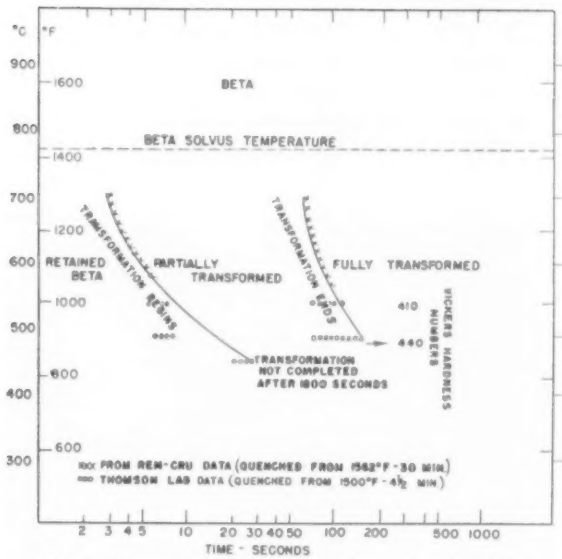


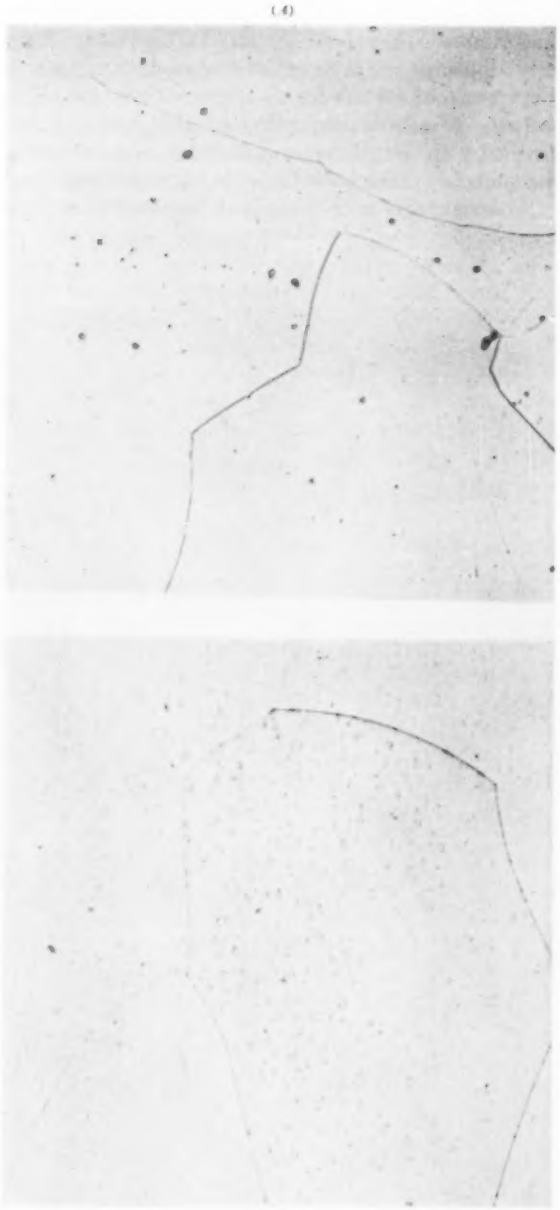
Fig. 5 Time-temperature transformation RC-130A

transformation of beta began after 30 sec, but was not complete after 1800 sec. In specimens treated at 910° F, transformation began at less than 6 sec and was completed between 60 and 120 sec. At the highest temperature obtainable in the salt pot, 1000° F, beginning of transformation took place in less than 6 sec, while transformation was complete between 60 and 120 sec. This information is plotted with previous data in Fig. 5; hardness values are listed. Typical microstructures at × 500 are shown in Figs. 6–9.

Since complete transformation and the lowest hardness was obtained in the shortest time with the maximum temperature employed, an isothermal treatment of 1000° F for 2 min was selected for use in further tests.

Fig. 7 Effects of time and temperature on RC-130A microstructure (quenched from 1500° F—4½ min. × 500)

840° F—30 sec. Significant transformation started (no change to 1800 sec).



(A)

(B)

Fig. 6 Effects of time and temperature on RC-130A microstructure (quenched from 1500° F—4½ min × 500)

(A) 650° F—1800 sec, all-beta structure. (B) 745° F—1800 sec, all-beta structure.

Inert-arc weld specimens prepared for heat treatment were extremely susceptible to cracking; many samples failed while still in the welding fixture or immediately after removal as shown in Fig. 10. In order to overcome this tendency, pre- and postheating at 300–350° F for 30 min were tried successfully. This temperature range should not be considered an optimum for all configurations.

It was planned to subject parent metal and butt welds made in 0.090-in. stock without cracks to the following furnace heat treatment in argon: 1500° F—4 ½ min; quenched to 1000° F—2 min air cooled.

Analysis of potentiometer data showed that specimens were held between 1490–1500° F for 5 min. However, difficulty was experienced in quenching samples to the lower temperature for the short periods of time involved. Measurements indicated that temperatures reached 1240° F in 3 min, and therefore, transformation has probably taken place before holding at 1000° F.

Although this heat treatment deviated from that originally planned, tensile and bend results were compiled. Bends were for face-bend specimens bent through the longitudinal weld axis; tensile tests were standard reduced section strips.

Bend results are tabulated in Table 1. Although the parent material ductility was adversely affected by the

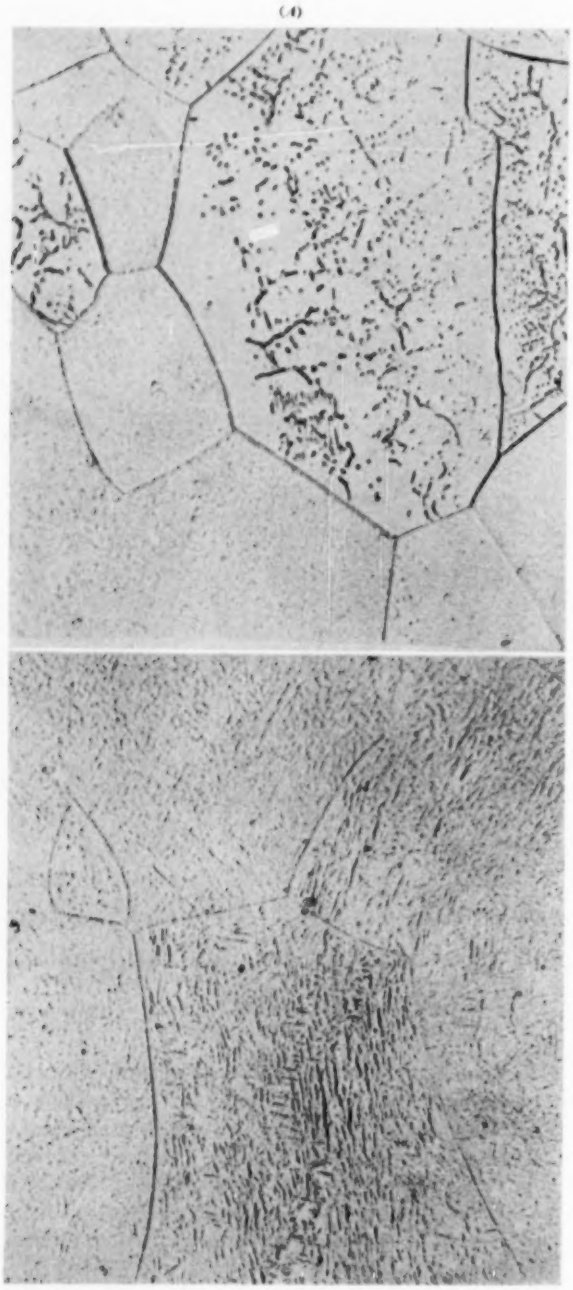


Fig. 8 Effects of time and temperature on RC-130A microstructure (quenched from 1500° F—4½ min. × 500)

(*A*) 910° F—6 sec; transformation started. (*B*) 910° F—120 sec; transformation essentially completed.

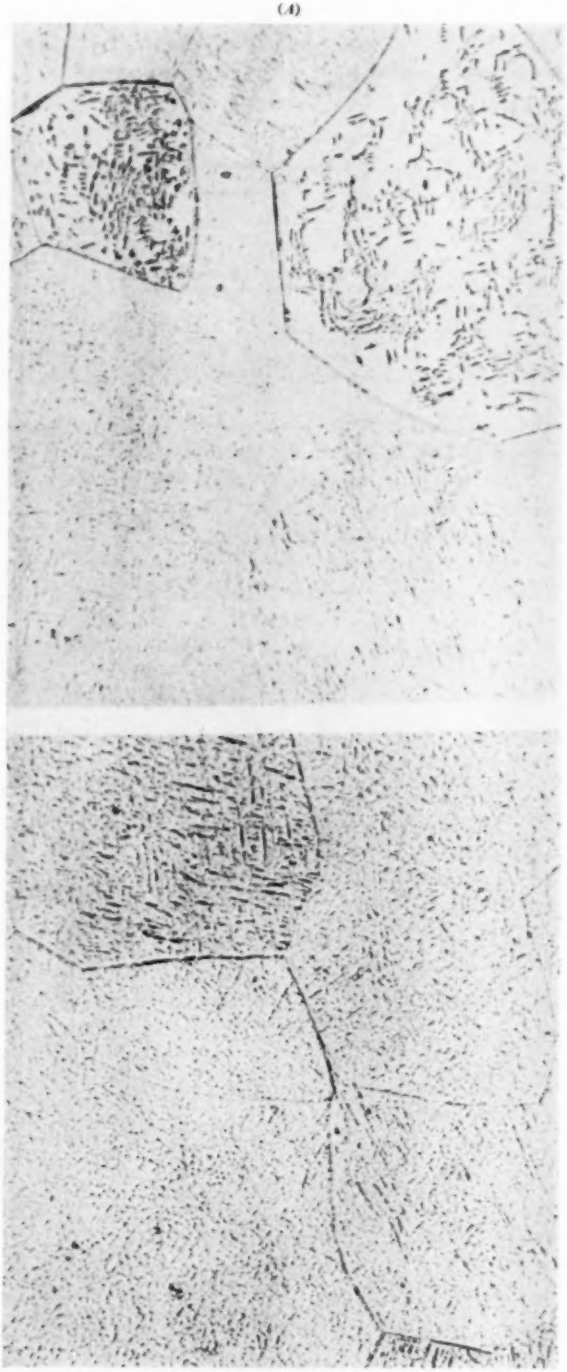


Fig. 9 Effects of time and temperature on RC-130A microstructure (quenched from 1500° F—4½ min. × 500)

(*A*) 1000° F—6 sec transformation started. (*B*) 1000° F—120 sec; transformation essentially completed.

Table 1—Longitudinal Bend Results for RC-130A

	Untreated		*Heat treated*	
	*1T**	*2T*	*1T*	*2T*
Parent metal	86°	180°	62°	80°
Welded joint	<5°	<5°	62°	40–49°†

* *T* = Material thickness.
† Gradual tear.

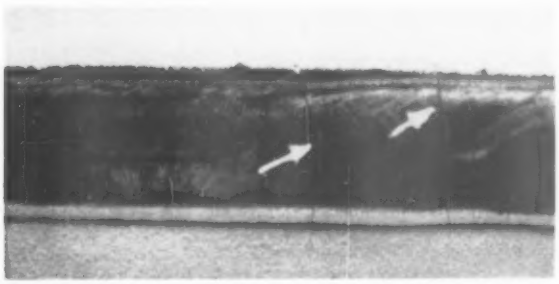


Fig. 10 Typical cracks in inert-arc welded RC-130 A (pre- and postheating was necessary to overcome this difficulty)

heat treatment and weld tensile elongation was poor (1.5%), the decided improvement in the welded-bend specimens over shadowed the other results.

Further testing was carried out on test pieces heat treated for longer periods of time to determine whether or not the times and temperatures involved were critical. Heating into the beta field was done at 1500° F for 4 to 17 min with cooling to 1000° F taking place in 10 and 15 min, respectively. A more sensitive bend test, one which involved bending transverse to the weld axis, revealed no differences for these varied treatments and an improvement from zero bend angle for an as-welded sample to 30 deg for heat-treated ones at *1T*, is shown in Fig. 11. The same bend results were observed in a weld section treated at 1550° for 30 min and held at 1100° F for 10 min.

As-welded joints possessed superficial Rockwell 15-N hardnesses of 86 (RC-51) in the weld and 72 (RC-43) in the unaffected parent metal. After heat treatment the entire weld area possessed uniform hardness level of 77–78 (RC-34,35).

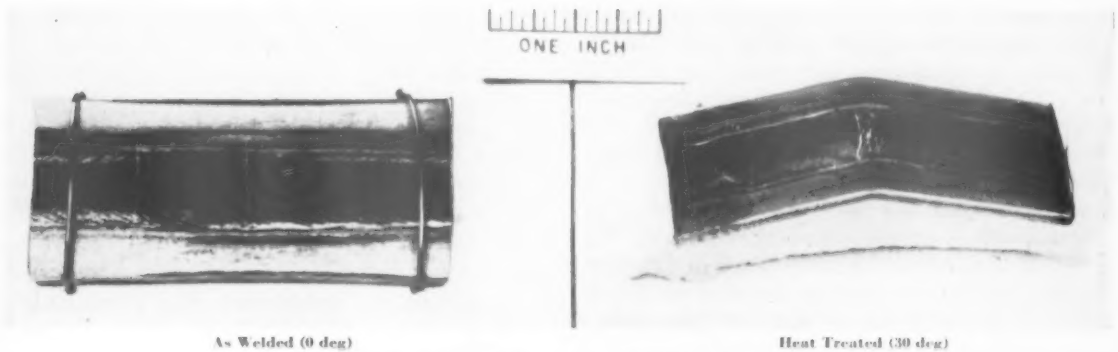


Fig. 11 Bend results at 1T, inert-arc welded RC-130 A

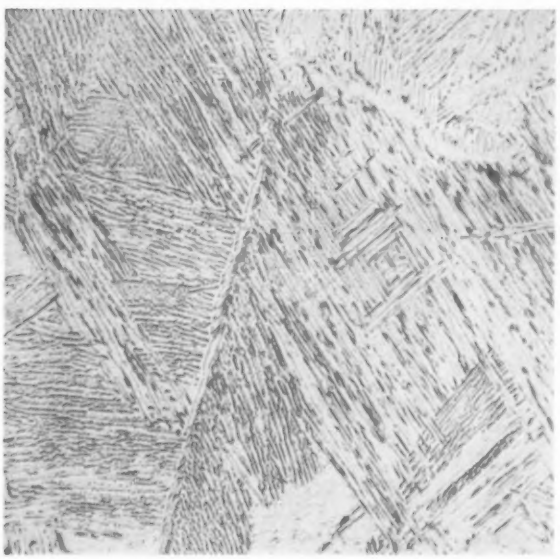


Fig. 12 Alpha plus beta structure in inert-arc weld furnace cooled from 1500° F. 500 ×

A welded sample heat treated in a similar manner was cold rolled approximately 20% in a rolling mill and subjected to tensile tests after a stress relief of 750° F for 30 min. Tensile strength was 147,000 psi while elongation was 4.1% (in a 3/4-in. gage length). Failure took place outside of the weld area in the parent material. The significant factor in this test was the ability of the welded joint to withstand the severe cold reduction imposed.

Consideration of these results and microstructure studies of isothermal transformation previously discussed, led to the belief that a slow furnace cool from the beta region might result in complete transformation and improvements in weld properties. Consequently welded joints were brought to 1500° F in argon, held for 4 1/2 min and furnace cooled to room temperature. Transverse bend angle at *1T* was 52 deg, while a longitudinal bend was 65 deg (comparable to the 62 deg in Table 1). Ultimate tensile strength reached 127,000 psi, yield strength at 0.0002 in. per inch was 90,000 psi and elongation in 2 in. varied between 4 and 7 1/2%. Microstructure is shown in Fig. 12.

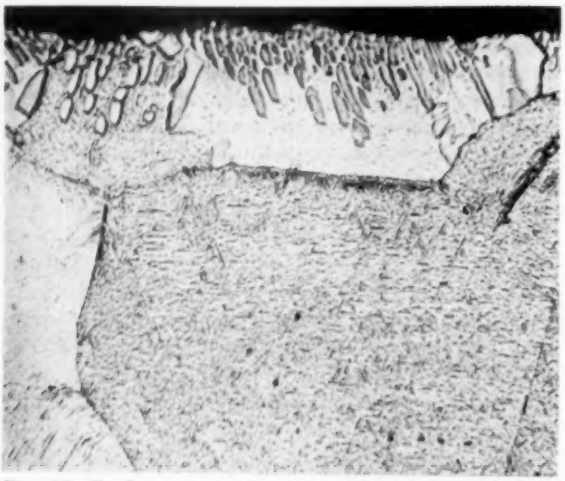


Fig. 13 Surface contamination evident in sample heat treated in air after sandblasting and acid cleaning. 500 ×

Tests were conducted by furnace heat treating samples in air to determine the effects of surface contamination. In general, oxidation resulted in an almost 40% reduction in bend ductility (19 deg at *1T*). Sandblasting plus acid cleaning in 10% HF for 5 min failed to remove all of the embrittling high-oxygen alpha layer as shown in Fig. 13. Hence, inert atmospheres are recommended at this time, unless improved cleaning procedures are developed. However, treating at lower temperatures does not require inert gas protection.

A welded specimen was placed in an 1100° F furnace for 30 min with no gas and allowed to cool in air. A longitudinal welded-bend specimen tested at *2T* failed gradually at an angle of 47 deg. Hardness was Rockwell C 35–37 uniformly throughout the sample, so that treating in the transformation temperature range indicated that ductile welds may be achieved without the need for increasing temperature to the beta field.

Because of the reduction observed in parent metal mechanical properties, any method which could restrict heating to the weld area alone would be beneficial. Toward this end, a welded joint was prevented from cooling below 1000° F for 5 to 10 min by torch heating immediately after welding. This sample bent 22 deg at *1T* (transverse specimen) and indicated enough improvement to warrant further studies. Oxidation of the surface or the differences in transformed structure from furnace-treated samples (see Fig. 14) may account for the decrease in bend angle from 30 deg.

At this point in the investigation, the heat of 0.090 in., RC-130A material was depleted. An order has since been placed for additional material and testing will be continued.

Concurrent with this investigation, Titanium Metals

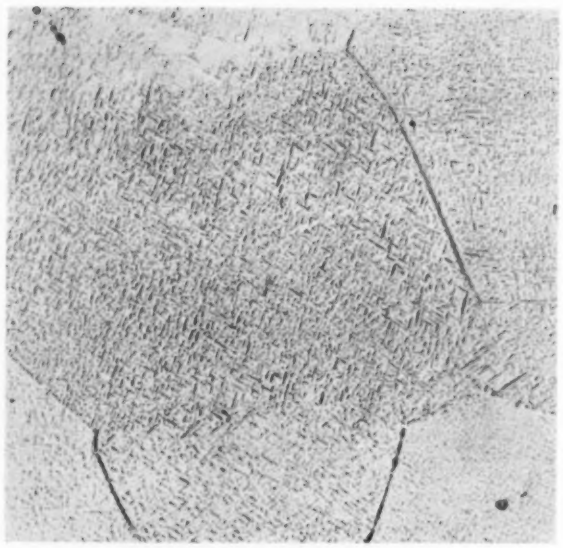


Fig. 14 Alpha-plus-beta structure in inert-arc weld torch heated immediately after welding. 500 ×. (Compare with Fig. 12)

Corp. alloy, Ti-140A,* was subjected to testing. Since no transformation data were available from the manufacturer, parent metal was studied for microstructure after heating in the beta region and quenching to 900 and 1000° F, respectively. The advantageous effects of transformation were exhibited for Ti-140A similarly to the RC-130A and heat treatment of this alloy will be fully evaluated at a later date.

RECOMMENDATIONS FOR FURTHER STUDIES

Tests should be continued on the effects of slow-furnace-cooling welded joints from 1500° F both in air and in argon.

Heat treatments in the transformation temperature range (950–1250°) should be fully evaluated.

The possibility of treating the weld area alone offers maximum hope of practicability in restoring weld ductility and efforts should be devoted toward this end.

Up to the present time, titanium's potential has been limited to low-strength structural purposes utilizing welded commercially pure material and to high-strength parts not requiring welding. The advance in welding technology discussed here points the way toward expanding the strength range of titanium grades available for welded parts and titanium alloys should now find wider application.

* Ti-140A, a ferro-chrome, ferro-moly titanium alloy now available commercially as forging bar, and sheet possesses mechanical properties similar to RC-130A.

Tricky Problems in Welded Ship Repair

Care analysis of suitable sequence in welding, proper use of preheating, suitable joint design and careful workmanship can help in solving difficult ship welding repair problems

by Milton Forman, P.E.

IN ITS fundamental principles the ship repair business is very much like all others. However, it does have some special features which make it different and which tend to intensify the problems usually encountered. Because a ship is taken out of active service in order to be repaired, there is a tremendous amount of pressure on the shipyard to make the repairs as rapidly as possible. Furthermore, many ship repair jobs are of an emergency nature, with the full extent of the repairs being determined only after the ship has been brought into the yard.

The very character of the work involved is spasmodic. Therefore it is extremely difficult for a shipyard to maintain a stable labor force that will permit the best continuity in work. Within the limitations of these two factors—the necessity for rapid turnaround and the problem of adequate qualified labor—the ship repair yard must gear itself to practices and operations which will assure the highest quality workmanship in the shortest possible time.

In order to achieve this result the usual methods of doing a job are not adequate. Better planning is of the utmost importance. The best type education of supervision and workmen is necessary in order that the best results may be achieved. The greatest ingenuity and initiative are required if the intricate problems of ship repair are to be solved.

Milton Forman, P.E., is Welding Metallurgical Engineer of the Brooklyn & Hoboken Divisions of the Todd Shipyards Corp.

Presented at the National Spring Meeting, AWS, Houston, Tex., June 16-19, 1953.

SHIP REPAIRS DIFFERENT FROM NEW CONSTRUCTION

In new construction very difficult welding problems face the shipyard. In many cases they are satisfactorily solved. In ship repair all welding problems become more difficult of solution. When building a new ship, relative freedom exists for welding contraction to take place. In the repair of a ship the work is always done in an existing, rigid structure. And since welding is always accompanied by shrinking and contraction the resultant problems are multiplied. In other words if welding is done to repair a deck, the deck itself will be put in tension while the attaching shell and bulkheads will be put in compression. The result can be distortion or fracture.

MAJOR SHELL BOTTOM RENEWAL

Figure 1 represents a typical example of major repairs

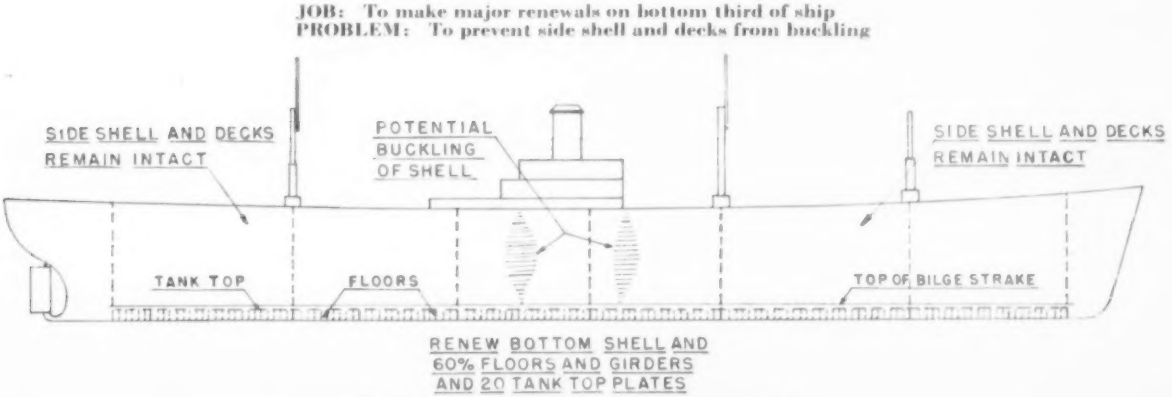

JOB: To make major renewals on bottom third of ship
PROBLEM: To prevent side shell and decks from buckling
SIDE SHELL AND DECKS REMAIN INTACT
POTENTIAL BUCKLING OF SHELL
SIDE SHELL AND DECKS REMAIN INTACT
TANK TOP
FLOORS
TOP OF BILGE STRAKE
RENEW BOTTOM SHELL AND 60% FLOORS AND GIRDERS AND 20 TANK TOP PLATES

Fig. 1 Bottom damage renewals on cargo ship

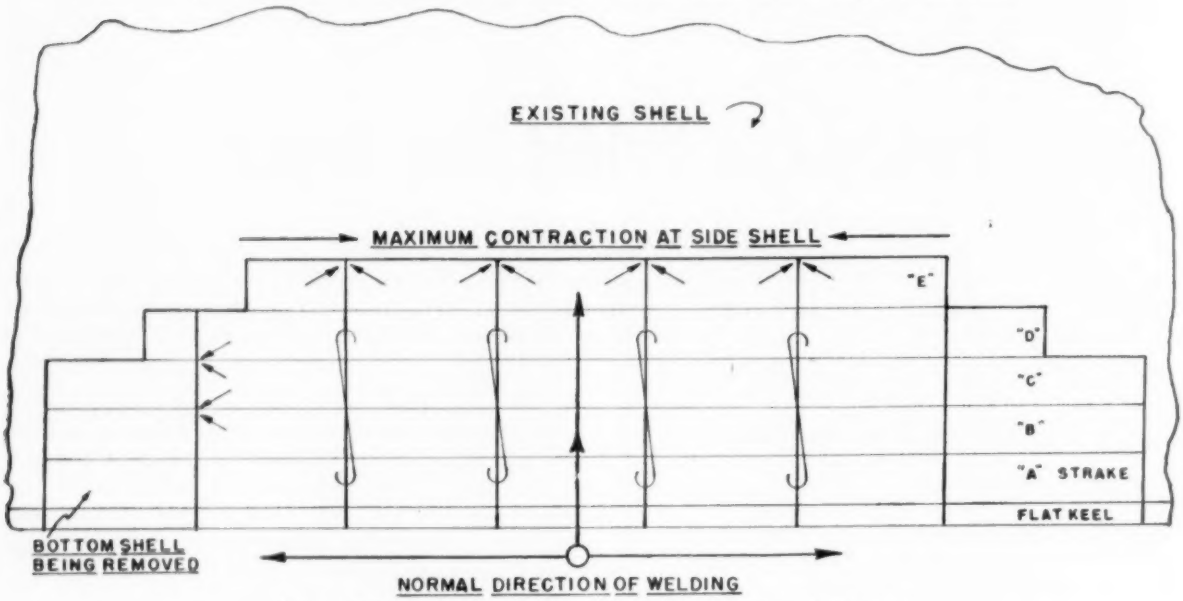


Fig. 2 Pattern of cumulative contraction on bottom-shell repair

which must be made on a ship. In this example the entire bottom of the hull has been damaged. The entire bottom shell, 60% of the inner bottom floors and girders and 20 tank top plates must be renewed. Assuming for a moment that the ship is a box girder, it will be noted that the bottom flange may be put in tension as a result of the renewals, the side shell is placed in compression and can develop buckling.

It has been reported by the American Bureau of Shipping that a number of this type of repairs have been made. It is further reported that invariably the side shell buckles. This buckling occurs either immediately upon the completion of the job or within a few months after the ship has been in service.

The Brooklyn Division of Todd Shipyards Corp. was given such a job. After representatives of the American Bureau of Shipping had alerted the yard as to the fate of most of these ships, a careful analysis was made before work was undertaken. First, the traditional sequence of welding was scrutinized. And Fig. 2 shows the pattern of cumulative contraction developed on the bottom shell. The standard sequence usually calls for all welding to start at midships and the centerline and progress fore and aft and outboard, attaching the new bottom plating to the side shell last. It will be noted as shown in Fig. 3 (*A*) that when welding starts at one end of the plate and progresses toward the other end, two types of movement occur. There is transverse shrinkage across the weld which pulls the two plates together. In addition the end toward which the welding is progressing shows greater movement and the gap closes even more. This is an often observed phenomenon, especially when heavy plates are welded. Therefore at the point where the new plating is to be attached to the side shell there is a cumulation of shrinkage from the many butt welds that is far greater than the transverse shrinkage of the weld itself.

In addition the longitudinal seams joining the bottom shell to the side shell are welded after the transverse

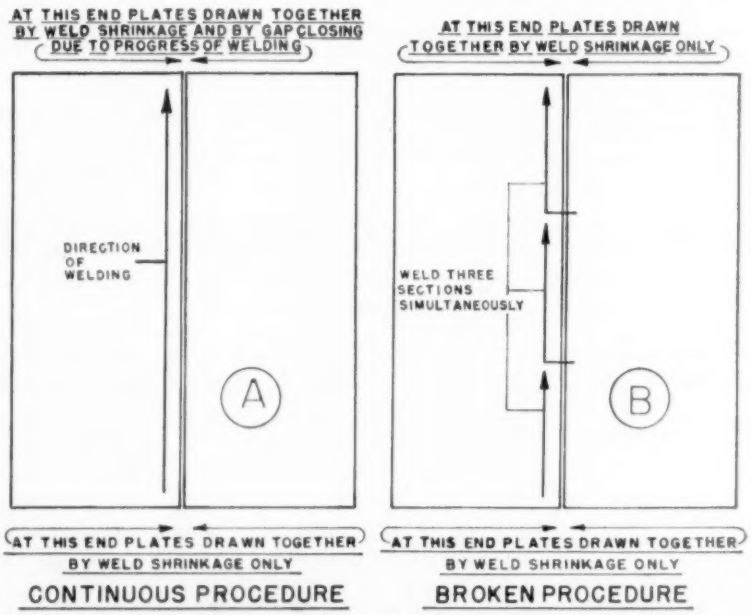

AT THIS END PLATES DRAWN TOGETHER BY WELD SHRINKAGE AND BY GAP CLOSING DUE TO PROGRESS OF WELDING
DIRECTION OF WELDING
A
AT THIS END PLATES DRAWN TOGETHER BY WELD SHRINKAGE ONLY
CONTINUOUS PROCEDURE
AT THIS END PLATES DRAWN TOGETHER BY WELD SHRINKAGE ONLY
WELD THREE SECTIONS SIMULTANEOUSLY
B
AT THIS END PLATES DRAWN TOGETHER BY WELD SHRINKAGE ONLY
BROKEN PROCEDURE

Fig. 3 Procedure to equalize shrinkage in welding along butt joint

welds are made, thereby causing added shrinkage stresses at that point. Also the longitudinal shrinkage of the other seams of the bottom shell act in a manner to tend to raise the keel. It is therefore logical to expect that the side shell immediately above the bilge strake would be put in considerable compression, thereby causing it to buckle. The problem therefore is: Can the normal weld shrinkage be controlled and used so that an excessive amount of compression is kept away from the side shell?

It is the opinion of the author that the welding shrinkage can both be controlled and made to work so that it decreases the tendency of the side shell to buckle. As noted in Fig. 3 (*B*) it is possible to develop a welding procedure which will allow two plates to be welded so that there is no closing of the gap at that end to which the welding is progressing. This can be done by simultaneously welding the plates at the ends and the middle. The transverse shrinkage itself is not eliminated. However, the directional shrinkage at one end is curtailed. Going a step further, if the welding starts at the outboard end and progresses inboard toward the centerline it is possible to develop slight tension at the outboard edge and slight compression toward the centerline. This can be achieved with a careful use of the "broken," backstep procedure shown in Fig. 3 (*B*). Also, if the vertical butt joints of the longitudinal girders are welded, starting at the tank top and progressing toward the shell, a tendency toward tension can be developed at the tank top.

In order to decrease the effect of the longitudinal shrinkage of the shell seams, the American Bureau of Shipping recommended that the seams be welded before the transverse butts. Therefore, the ends of the seams would contract and the only shrinkage stresses transmitted to side shell would be the transverse shrinkage of the butt welds. In order to achieve this, 24-in. cutbacks were to be made into the existing shell at the outboard ends of the transverse butts.

Keeping the above in mind the following sequence was devised and is shown in simplified form in Fig. 4: (*a*) All welding was done on the internals and tank top before the shell plating in that area was erected. A cut was made in Hold 3 across the entire tank top permitting the tank top to contract. After all welding had been completed on the tank top it was recorded that the gap had opened $^1/_2$ in., indicating that the tank top had shrunk that much because of the welding. (*b*) All seams were welded and the internals were welded to the shell between the transverse girth joints. The seams were first welded to the side shell and the flat keel, with the result that the final erection joint was between the *C* and *D* strakes. This meant that the longitudinal seams welded under the greatest restraint were removed from the side shell. Also the above-described welding was done simultaneously in all sections of the bottom shell, therefore allowing a maximum of men on the job without overcrowding in any particular area. It will be noted that the shrinkage from this mass of welding was distributed throughout the bottom avoiding a cumulative effect. (*c*) The final transverse butt welding progressed simultaneously from midships fore and aft and from bow and stern toward the two expansion joints shown on Fig. 4.

In order to eliminate the tendency for root cracking in the butt joints a modified block welding procedure was used as shown in Fig. 5. This procedure permitted a substantial section of the weld joint to be deposited in a relatively short time, a sufficient amount to prevent the often encountered root cracking. Incidentally, this supplied a certain amount of preheat for the second and third passes.

When this job was completed, the side shell and the

To decrease compression in side shell reverse sequence of welding

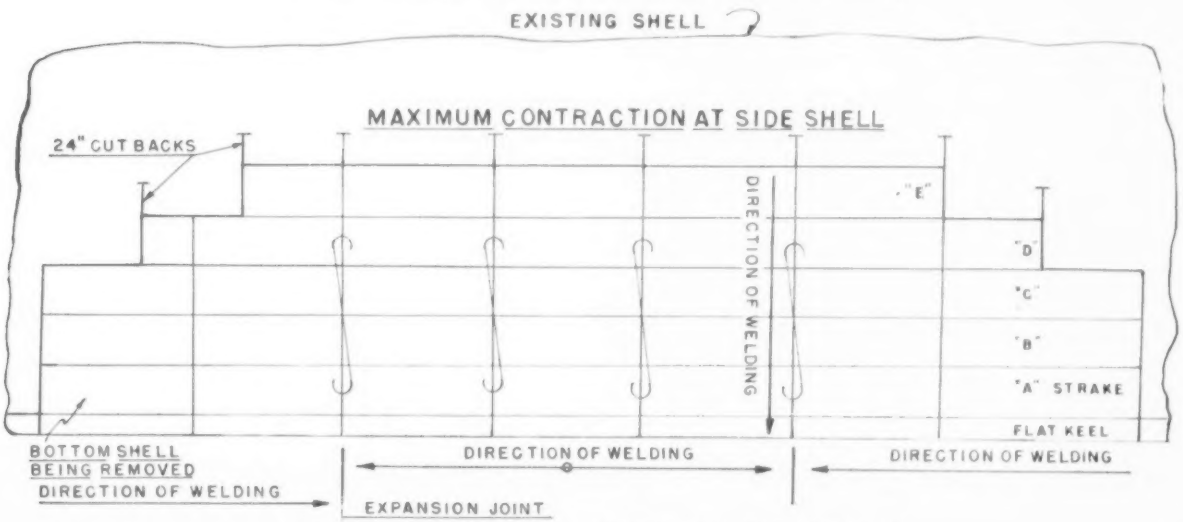


Fig. 4 Pattern of cumulative contraction on bottom shell repair

Notes: (1) All welding between girth butts to be made before girth welds are made. (2) All longitudinal seams are to be welded before transverse welds

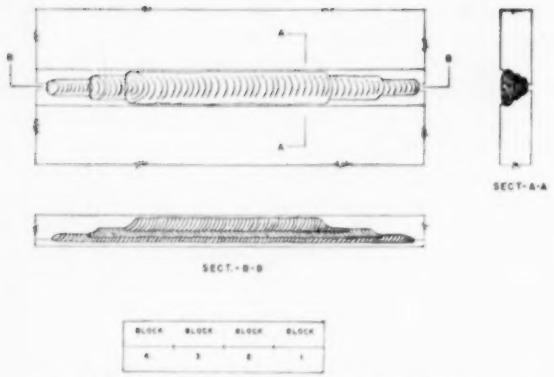


Fig. 5 Modified block weld procedure

decks were carefully checked and in no case had buckling developed due to this extensive welding. The ship has been in service for some time and reports indicate no change in the condition of the side shell or decks.

RENEWAL OF ALL INTERNALS ON TANKER

The Hoboken Division of Todd Shipyards Corp. was given the job of renewing practically all the corroded internal members of a large tanker. As shown in Fig. 6, this included the main longitudinal bulkheads, the transverse bulkheads, the web frames, centerline girders and the majority of the longitudinal framing. For all practical purposes everything was renewed except the shell and deck. This job was to be done in two major stages: (1) In the water where all renewals above the water line would be made; (2) on the drydock where the renewals in the bottom third of the ship would be done.

The problem that faced the shipyard was to prevent the ship from developing a sag or hog and to maintain a fair ship without buckling. Considering the fact that the first stage referred to above would require a large quantity of unbalanced welding at the top flange of the vessel, it is evident that this was no simple problem.

The design of the vessel was carefully analyzed and by mutual agreement with the shipowners it was decided to renew all bulkheads with lap weld construction instead of butt welding. Although, in new construction, it may be more desirable to use butt weld construction, it has been the experience of the author that lap weld construction is preferable when making large scale renewals. In addition to making it easier to erect and fit large assemblies into an existing ship, the shrinkage from welding lap joints is much less than from welding butts.

The deck plates immediately above the longitudinal bulkheads were removed in order to facilitate the removal of the old bulkheads and the erection of large bulkhead assemblies. In fact the basic principle of erecting large preassembled sections was used throughout. This represented quite a problem in the hold immediately below the deckhouse. And it was as a result of an ingenious device developed by Todd's Hoboken Division that the longitudinal bulkheads in way of this deckhouse were removed and erected in one piece. A simple rolling method was developed which permitted the bulkheads to be lowered into the after hold and rolled forward into place under the deckhouse.

In removing the old structure, care had to be taken to maintain sufficient longitudinal strength in the vessel. A careful schedule of removal and replacement was devised to achieve this. Readings were taken over the length of the ship during the progress of the job to determine that the original position of the deck was maintained.

The welding sequence was designed to follow the basic erection plans and certain lap joints on the longitudinal bulkheads were left free to allow for weld shrinkage. It was observed that this shrinkage took place and periodically the tack welds would break at these expansion joints. In order to develop a tendency of tension at the main deck and compression below, all vertical welding started at the top deck and progressed toward the keel using the backstep method.

At the start of the job the size of the required welds was carefully reviewed and, making sure that they ful-

JOB: Renew all bulkheads, transverse webs, longitudinals on deck and shell and centerline girders
PROBLEM: To keep remaining decks and shell from buckling and maintain fair ship

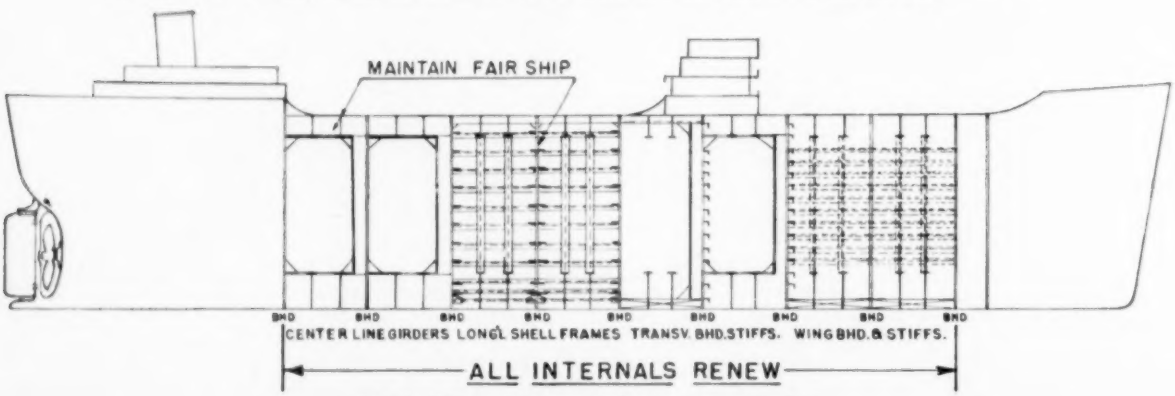


Fig. 6 Renewal of corroded internals on tanker

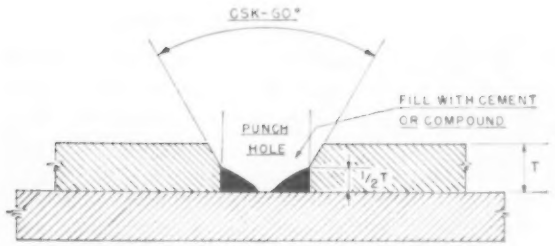


Fig. 7 Recommended detail for plug welding

filled ABS requirements, the welding was kept to a minimum. In all cases, despite different original opinions, the shipowner cooperated fully in helping to decrease the amount of welding. In another case the amount of welding required in plug welds was reduced. Figure 7 shows the recommended Todd practice for welding plugs. The reduction of the quantity of welding, although great, is secondary. What is more important is that the quality of the plug joint is assured. The hole shown in Fig. 7 is filled up only after the adjacent tank has been tested. The quality of the weld itself is easily inspected and faulty work, so usual in plug welding, is eliminated.

Even though the American Bureau of Shipping and the shipowner had inspectors on the job, the yard set up its own simple but thorough inspection system. This resulted in practically no pick-up welding being found by the outside inspectors.

Because of careful planning and control, the work on this ship was completed economically and in good time, no distortion developed and all hands were satisfied with the job.

GIVE THE OWNER WHAT HE WANTS?

At a local meeting of the Society of Naval Architects, a shipyard representative made the remark "Give the owner what he wants." This attitude on the part of shipyard personnel bears analysis. It is undoubtedly true that in a most basic sense the owner should get what he wants—a sound ship. However, it is not always true that all of the proposals that the owner makes are the best possible proposals which achieve this end. This is no reflection on the competence of the shipowner's representatives. It merely means that some shipyards may have specialists who can suggest newer and better practices. And it should undoubtedly be the responsibility of such a shipyard to give the shipowner the benefit of its experience and personnel.

SHOULD THE SHIP BE KEPT "AS IT WAS?"

Most of the ships being repaired today were built long ago. In many cases the design practices of today are superior to those of the past. And the question arises whether the repairs should be made according to the old design or according to newer and better practices. With reference to the bottom shell renewal job previously mentioned, the original ship had been welded continuous throughout. To replace this large quantity of continuous welding meant that the danger of distortions on the existing, rigid hull would be increased. The shipowner was quickly convinced that he would get a better job, a fairer ship, with the use of intermittent welding on the internal members.

In another case of an old ship the inner bottom floors were attached to the shell with an angle as shown in Fig. 8. Would it not be a more efficient joint to replace the floors to be renewed with a joint as shown on the right-hand side of Fig. 8? This would result in less welding, less weight, greater strength and higher quality of welding. And despite the fact that some floors would have a slightly different joint detail, the ship itself would be as strong or stronger than the original. It is not logical reasoning to say "make it as it was." It is much better sense to say "do the best you can with your present knowledge."

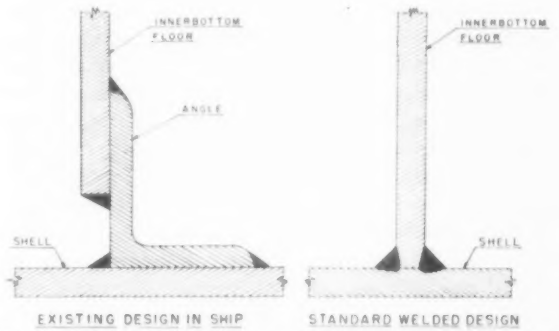


Fig. 8 Should renewals be made to conform to outmoded designs?

It cannot be said that the responsibility for the use of outmoded designs and practices is in the hands of the owners or inspectors alone. Experience has proved that the shipowners, the American Bureau of Shipping and other regulatory bodies, as well as the shipyards, are eager to cooperate when sound suggestions are made which improve the work. What is required is an alertness on the part of qualified personnel toward making improvements, and a determined desire to avoid the line of least resistence—"give the owner what he wants."

MAKING A FETISH OF WELDING SEQUENCE

Although the experience of World War II should have been ample proof that there is more than one way to weld a job, hangovers still exist that *one welding sequence can be the best welding sequence.* As long as the welding sequence fits into the larger picture of the basic fabrication and erection plan of a given yard it can be made to be satisfactory. Yet it still happens that a contract is written which dictates a basic aspect of a welding sequence. An example of this can be sighted when recently some barges were to be built. In this case the contract read that all welding was to be completed with-

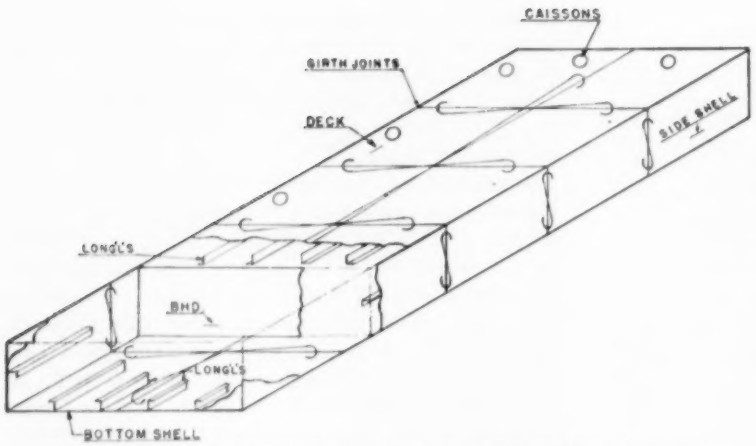


Fig. 9 Hypothetical barge showing many possible welding sequences

Note: Any number of satisfactory welding sequences can be developed to weld this structure

in any girth section (as shown on Fig. 9) before the transverse girth joints could be welded. In addition it was specified that the deck bottom shell and side shell must be welded simultaneously. An examination of Fig. 9 makes it quickly evident that any number of satisfactory welding sequences could be devised to properly weld such a simple structure. For example: The bottom shell could be welded together in whole or in part; the side shell and deck could be welded in similar fashion and then all these could be joined together with the proviso that no unwelded butts be crossed and that the welding proceed on port and starboard sides simultaneously. If the erection and fitting proceeded according to the original schedule no changes in any given sequence would be required. However, if changes in the erection were necessitated, then the welding sequence could be easily changed to suit. The main point is that there is no justification for limiting any shipyard to a preconceived welding sequence.

WORKMANSHIP

There is prevalent a false opinion that once the inspection agencies pass a job, the shipyard is relieved of responsibility. Most important, the yard has the responsibility of protecting its reputation. Some people have expressed the opinion that a ship repair yard ought to "guarantee" its welding by the use of Radiographic Inspection. If this becomes standard practice, the shipowners will in the long run have to pay for this additional inspection device. The only way to save the shipowners this expense is for the ship repair yards to develop methods, procedures and control *in the process of doing the job* which prevents any one from casting any reflection on the quality of their work. This is not an impossible job. On the contrary, it is very desirable under any conditions.

Welding has proved itself a thousand times in the construction of new structures. It has permitted better designs, more economical and stronger ships to be built. The repair of these vessels has followed in the same tradition and as time goes on even greater progress will be made.

ACKNOWLEDGMENTS

The work described in this paper represents the collective experience of the managers, engineering department, supervision and workmen of the various divisions of Todd Shipyard Corp. Mr. Jim Kristan is responsible for the drawings.

WELDABILITY OF STEELS

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Magnaflux for Quality Control of Pipe-Line Welds

Quality control in pipe-line welding can be used to improve welder technique, electrode selection for specific jobs and to improve pipe-line construction

by George L. C. Dehn

THE use of an organized program of process and procedure control has grown immensely since about 1945 and is being recognized as the latest powerful development of a functional type to improve the accomplishments of management, engineers, inspectors and production men alike. Quality control by means of process control is foremost in the minds of management today. This is true throughout all branches of manufacturing and assembly industries. It has become a strong force for saving money and avoiding trouble and waste in many welding operations as in other industries.

NEED FOR QUALITY CONTROL

In general welding, and in pipe-line welds in particular, those who have installed a quality control method find that it shows ways to improve welder technique, selection of the best rods for specific jobs and still broader ways to improve pipe-line construction. It is then not necessary to assume that a certain percentage of welds will be faulty and must be repaired. This decreases the number of repairs necessary after pressure testing, or after the line is put to use. The same method of quality control can be applied to troublesome locations such as valves, fittings and the piping in and around compressor stations. The same philosophy of control applies to both construction and preventive maintenance, surprisingly enough.

Constant, alert control is necessary. The greater the possibility of trouble, the sooner a quality control method using magnetic particle inspection should be instituted. Cast steel fittings and valve bodies are inspected in troublesome areas before being placed in position. Forged fittings in and around compressor stations and pumping stations are inspected for forging laps and other possible discontinuities prior to their being welded into lines. Inspection of such parts prior to their being placed in position can result in either repair or replacement of the part without the necessity of taking these parts out of a completed line or system and replacing them with new pieces.

Quality control will help improve procedures and processes by showing when and where these procedures and processes are failing, causing defective discontinuities. Good inspection methods can make process control more effective. Inspection of stringer beads during pipe-line construction permits immediate chipping and repair of defective welds. When subsequent welds are finished, assurance can be had that these welds will not be found defective because of discontinuities in the stringer bead.

On a recently completed pipe line it was found by the use of quality control methods, after various handling methods and welding procedures were corrected, that welds containing detrimental defects were reduced 84%. The defective welds were made evident by magnetic particle inspection. Then the causes of defects were isolated and corrected by thoroughly analyzing the cause for such defects developing. Equally satisfactory results can be gained elsewhere.

The general trend toward utilization of materials at higher stress levels and lower factors of safety is also being employed in pipe lines today. This all leads to more need for a good thorough quality control method to reduce costs and increase safety. In pipe lines, uninterrupted service is an absolute necessity. Downtime even after the lines are completed and in operation has been proved to be greatly reduced with the use of a good quality control method.

MAGNAFLUX METHOD

While Magnaflux is still a relatively new word to most pipe-line personnel, it is an old and well-recognized method of inspection in weld shops and in the field where highly stressed parts are fabricated or high-alloy welding is performed. Inspection with Magnaflux, more commonly known as magnetic particle inspection, has been specified by many chemical plants and refineries during fabrication of vessels and piping to be used under high temperature and pressure. It is used for inspection of high-alloy welds not only for

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defects in the weld itself but also for cracks which might have developed adjacent to the weld in the parent metal in the heat-affected zone. Welded structural buildings, bridges, ships, casting repairs, man-way and nozzle openings, highly stressed areas of storage vessels, aircraft welding, Diesel crankcase welds and numerous other single and multiple pass welds are inspected by the magnetic particle inspection method. These fall into the category of structures which are stressed by temperature, loading, vibration or other means. In many other cases, magnetic particle inspection is of value for safety and economic reasons because it is inexpensive, simple and rapid. In some cases 100% inspection can be performed for less than one-fifth the cost of other types of inspection. In other words, 100% inspection with magnetic particle methods will cost approximately the same as 20% inspection by other known methods for finding similar types of discontinuities.

The application of this inspection to welds and other fabricating methods is relatively simple, and consists of two basic steps: first, magnetization of the area of the material to be inspected; second, application of finely divided magnetic particles either dry or suspended in a liquid over the surface of the magnetized part. If a discontinuity in the material lies where it is an obstruction to the magnetic lines of force, some of these lines are crowded out to the surface and act like horseshoe magnets to attract and hold the magnetic particles.

These magnetically held particles form a highly visible indication which outlines the location and the extent of the defect. A discontinuity usually is not visible until an indication forms along its length to disclose it to the observer. The particles slightly magnify the discontinuity in order to increase its visibility.

Magnaflux was developed over 20 years ago and its first usefulness to industry was visualized in the twenties by the late Professor A. V. DeForest of Massachusetts Institute of Technology. Acceptance by industry was necessarily slow at first. The method had to prove itself by accomplishment. These accomplishments have been due to several characteristics: first its relative simplicity in principle; second, the ease by which it can be applied; third, the almost complete freedom from restriction as to size, shape, composition and condition of the material to be inspected. The only over-all restriction is that the method, by its very nature, is limited to magnetic material.

Operator training is essentially important and the Magnaflux Corp. has instituted a series of schools and training courses to bring before its users the best techniques and proper applications of magnetic particle inspection. These operators are periodically put through schools and trained to inspect particular items so that they do not become lax in their procedures. Rather, they become deeply interested in the underlying metallurgical or fabricating causes of defects. Many companies using magnetic particle inspection have instituted their own program of personnel training, and later

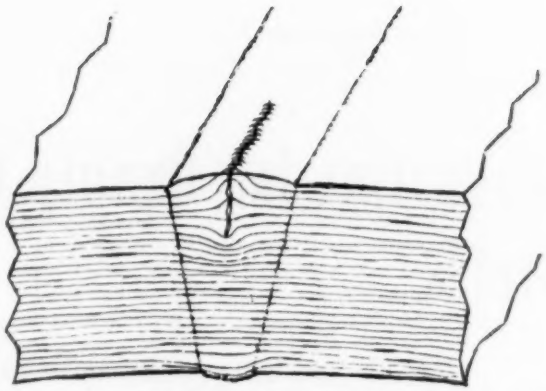

Fig. 1 Path of magnetic field with surface crack in weld

have followed it up by an on-the-job training period under the watchful eye of an experienced supervisor. Such continual training assures the contractor and the pipe-line company of excellent and efficient inspection. This is accomplished in the same way that welder training schools are conducted and followed up by on-the-job training in the field.

TYPE OF CURRENT

Various types of currents might be employed for the use of magnetic particle inspection, but through research and use in the field it is found that there is only one type of current suitable for producing the best indications of the discontinuities appearing in welds.

Originally, direct current had been used for many years with full success on surface cracks. Its usefulness for also detecting the subsurface defects was more unreliable and limited, primarily because of the lack of mobility of magnetic powder particles. When these particles were applied to the surface, it was necessary to use air to move the particles or remove excess particles from the surface. When air was used to blow away excess powder, it was found that weak indications would also be blown away, whereas indications built up by mechanical means, such as at the root of a ripple in a weld, would be held tightly. In this way it was possible to miss an indication of a discontinuity which may be detrimental and should have caused rejection.

Alternating current provided the mobility of the particles and produced exceptionally good indications quite readily without the use of air. Weak indications were built up with no loss due to air used for powder removal. However, because of the skin effect of alternating current, the alternating field does not permit the detection of subsurface discontinuities. Only surface cracks or openings at the surface can be found by its use.

After much research, the use of a half-wave, low-voltage, high-amperage, pulsating direct current was developed to provide deep penetration of a magnetic field and to provide mobility to the powder particles. After experimentation, it was found that deep-seated subsurface discontinuities could be found with the use

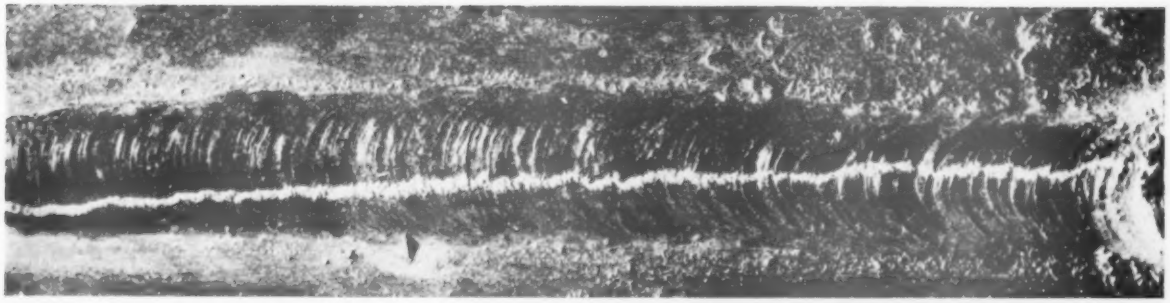

Fig. 2 Magnetic particle indication of surface crack in weld

Fig. 3 Magnetic particle indication of surface crack in weld

of this half-wave direct current which could not be found by ordinary direct current. Also the use of half-wave direct current of the low-voltage, high-amperage type, helps to build up a prominent indication as soon as any powder particles are applied. Because the voltage is low, there is less likelihood of arcing; the current is absolutely harmless and cannot in any way be injurious to the operator. The operator, while applying the magnetic field and the magnetic particles can watch an indication build up and therefore do a rapid magnetic particle inspection.

The type of magnetic field developed in the weld by the use of high-amperage, low-voltage, half-wave direct current might be shown as illustrated in Fig. 1. This field is shown being obstructed by a surface crack or discontinuity, causing a leakage field at the surface which attracts the particles of magnetic material. These particles form a sharp and well-defined indication, or powder build-up, because the leakage field is sharp and well defined. Such an indication would be the type as shown in Figs. 2 and 3, which are actual magnetic particle indications of a surface crack in a weld.

If a discontinuity were below the surface, it would affect the magnetic field as shown in Fig. 4. This shows the manner in which a magnetic field is distorted by a subsurface discontinuity creating a wider or broader leakage field at the surface. This leakage field again acts like individual horseshoe magnets and attracts the powder particles forming an indication over the defect. Because the leakage field is wide and flat, the indication is wider and fuzzier than the indication formed by a surface crack. This type of an indication is a definite signal that the discontinuity is below the surface. The type of powder build-up is determined by the depth and extent of the subsurface discontinuity. Such an indication is shown in Fig. 5, which is a slag inclusion in a weld.

The use of high-amperage, low-voltage, half-wave direct current provides deep magnetic penetration and increased mobility of the powder particles. It is possible to rapidly detect subsurface discontinuities such as inclusions, lack of penetration, root cracks in one of the weld passes or a crack which may be in the stringer bead or hot pass. Such indications would be as shown in this figure. Suitable equipment is truck mounted and operated by two men, a helper and an inspector, who are able to keep pace with ten to twelve welders working in line, in addition to checking any tie-in welds. This is performing 100% inspection on all welds made in the field. On-the-line welding accounts for a majority of the leaks ordinarily found during final pressure tests. Though defective welds may be extremely few, it is highly important to inspect these welds on a quality control basis to determine

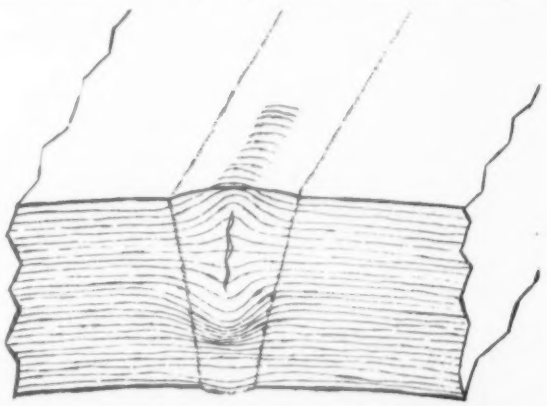

Fig. 4 Path of magnetic field in weld with subsurface defect

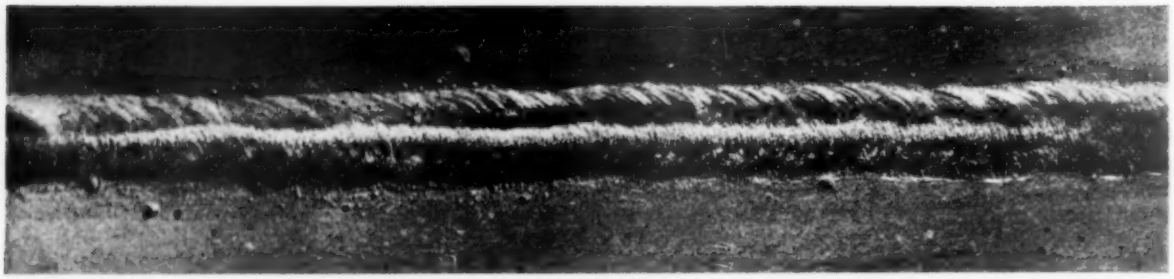

Fig. 5 Magnetic powder indication of subsurface defect in weld

which welds are defective and which operators and welders require the closest control. One hundred percent inspection provides more assurance of quality in this case than could be expected from any spot check or sampling inspection method.

INSPECTION ASSISTS IN PRODUCTION

Not only is magnetic particle inspection performing the service of insuring better welding, but the handling operations after joints are welded together above ground can also be improved. Raising or lowering or improper blocking when the joints are lined up for welding may also cause cracks to develop. These cracks, when found by inspection, are traced to the causes so that correction is made prior to a great number of lengths of pipe being welded together and lowered in the ditch. The time to find the difficulty and correct the procedure is as it happens. By eliminating causes of defective welds, assurance is had that these joints will not leak on pressure testing nor after they are covered and the line completed.

In one particular case, a company that had been using magnetic particle inspection for inspection of pipe-line welds, the inspector located powder indications on several welds that indicated a lack of penetration. Each weld stamped by a metal stamp to identify the welder told the inspector that all welds had been made by the same man. The indications of lack of weld penetration told the inspector that perhaps a larger rod had been used on the hot pass than was specified. Upon investigation it was found that the magnetic particle inspector was correct. This lone welder had substituted a larger rod than had previously been specified.

Another company using magnetic particle inspection of pipe-line welds started to check for accuracy by cutting out and testing coupons destructively. They were not convinced magnetic particle inspection was accurate. When magnetic powder indications or build-ups were noted, coupons would be cut and the presence of slag pockets, undercuts, lack of penetration and other discontinuities closely correlated. After a number of such tests, only an occasional coupon was taken from very questionable welds. Now magnetic particle inspection is relied upon fully to locate any of the discontinuities which would later fail either during the final pressure test or while the welds are in service. The individual pressure bubble tests originally performed as standard procedure were reduced, and when eliminated, further reducing inspection costs.

PIPE LINE FAULTS

A location which quite frequently gives a great deal of difficulty is the junction of the longitudinal weld and the circumferential weld. Magnetic particle inspection can be used on pipe lines in the field to inspect this junction. When the Magnaflux inspector is inspecting the circumferential weld, he can very easily change the location of his magnetizing contact prods, placing them along the longitudinal weld to inspect 12 to 18 in. along the weld and locate any discontinuities which might be present.

It is known that plate may contain laminations and occasionally these laminations are at the edges of the plate. When the plate is rolled and made into a piece

Fig. 6 Weld with ground area showing subsurface slag

Fig. 7 Inspection truck on a spread

of pipe, the laminations might be at the end of the pipe. Such laminations, if they are extremely large, cannot be burned out by the welders and consequently will cause the weld to crack upon cooling. A quality control inspection can be performed and should be performed on suspected lengths of pipe or on lengths of pipe selected by random sampling. It is exceptionally easy to perform this inspection since the magnetic particle inspection truck can be readily moved to any location. An immediate answer can be obtained by inspecting the beveled edge of the pipe to detect these laminations that come to the surface.

On a crude oil line where inspection was being performed, several stress cracks were found near the bottom quadrant of the weld. Upon further investigation, it was found that the line-up gang was rough handling the pipe and not waiting until the stringer bead welders were finishing the stringer bead before setting the pipe down on skids. By further instructing the handling crew, these stress cracks were eliminated and only periodic inspection was performed on the remaining welds. This was not a case of poor welding but only in the method of handling and moving the pipe at the improper time. When such methods are corrected, discontinuities can be eliminated with worth-while savings.

In one day on this same line, seven welds were found to contain cracks. The weld inspector was informed and he immediately noted the numbers stamped on the pipe of the welders performing these welds. After watching these welders for a short period of time, it was discovered that one welder was using a higher current range than the other welders. After changing the men around and adjusting the welding machines properly the cracks were cut out, welds repaired, reinspected and found to be free of defects. A short period of instruction by the weld inspector along with correcting other difficulties eliminated future cracks among this group of welders. By controlling the size of rod, the output of the welding machines and the speed of the welders, such difficulties can be immediately eliminated and time saved by not having any larger number of defective areas. Among another group of welders, it was also found that their procedures were not correct. Correcting the procedure of this group of welders prevented further recurrent cracks from being developed.

On the next several days of this pipe-line work no defects were found at all that would be considered detrimental to the pipe-line welds. On the seventh day one crack was found near the bottom quadrant but no particular cause could be isolated. Two days went by without finding any further detrimental discontinuities although the temperatures were quite low and the ground slightly hilly. The next day two defects were found in two successive welds. Upon investigation it was found that the handling crew had let the

Fig. 8 Magnetic particle inspection of pipe-line weld

Fig. 9 Magnetic powder indication of subsurface defect in weld on pipe-line job

pipe drop the last 6 in. onto the skids, which, apparently was the cause of the development of these two cracks. Further caution was given to the handling crew and from then on no cracks were found that could have been caused directly by handling of the pipe after the stringer bead had been laid.

The next day two successive welds produced magnetic particle indications of cracks. After surveying the situation, it was decided these two cracks were caused by exceptionally hilly ground and the fact that the pipe was not curved enough to follow the contour of the ground. A warning was given to the bending crew, and it was found that the cracks had been caused by a miscalculation, the pipe not having been bent sufficiently to fit the contour. From then until the job was completed, no discontinuities of any type were found which would have been considered detrimental to the welds in this pipe line.

One joint of pipe on this line was found to have produced indications of subsurface cracks in the longitudinal fusion weld when magnetic particle inspected. This was discovered when the end of the weld was inspected adjoining the circumferential weld. It was decided by the welding inspector that this joint of pipe should be cut out and replaced.

As a summary of this complete job, it was found that four cracks were found due to improper handling of the pipe. The first day the cracks were located because the handling crew was trying to rush the job and laying down the pipe before the stringer bead welders had finished. The other two cracks that could have been laid to the handling crew might have been an accident but a warning of more careful handling of the pipe was well in order. On the second day seven defective welds were found, all due to faulty welding. After closer supervision and some corrections made by the weld inspector, the defects were eliminated by this crew. The third day produced four welding defects and after suitable corrections, this crew likewise became more proficient. Later only one crack was found to be due to faulty welding but two cracks were found to be due to faulty bending of the pipe to fit the contour of the ground.

In order to more closely look at the results, thirteen defective welds were found in the first three days of laying this line. All of these defective welds could be and were repaired. However, repairs are expensive. By correcting the procedures which caused these difficulties, further repair was unnecessary, thereby reducing the costs of laying the line. The balance of the inspection and laying of this line consisted of three-fourths of the remaining time. During this time only five defective welds were found, two of which could

Fig. 10 Inspection on the job

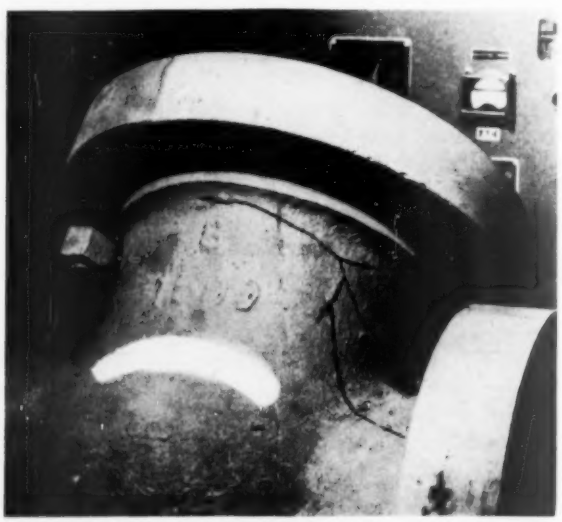

Fig. 11 Magnetic powder indication of crack in valve body

have been attributed to an accident, two to carelessness and one might have happened to any welder. This accounts for 72% of the defective welds in the first 30% of the time, and the balance of the 28% in the final 70% of the time involved in construction of this pipe line. Detrimental discontinuities were reduced 84%.

Quality control can be sensibly and simply applied to pipe-line welds by locating the cause of the defective welds at the start of the job. In order to work out a quality control program, definite procedures must be set up and the cooperation of all operators and supervisors is necessary. By doing so, a pipe line can be completed free of detrimental discontinuities and a good quality control standard can be organized when magnetic particle inspection is used.

IN CONCLUSION

As a result of a great amount of research work and numerous completed inspection jobs, inspection with Magnaflux has been found to be a rapid, inexpensive, nondestructive method of quality control.

The foregoing is an excellent example of what is meant by quality control of pipe-line welds with magnetic particle inspection. The welds are inspected, the defects found and corrective action taken. There is a reduction in faulty welds which eliminates all of the necessity of chipping, repairing and reinspection. Aside from this, there is assurance that the welds are free from detrimental defects when the line is pressure tested. Also it will not be necessary to later go back and repair any welds along the entire line.

The ideal time to perform the inspection is after the stringer bead has been completed so that detrimental discontinuities can be found, chipped and repaired, without removing an excessive amount of completed weld.

You are all familiar with the higher stresses, the vibration and the cost of a possible failure of welds in and around compressor and pump stations. Quality control as described above is equally applicable to piping and fittings during construction or maintenance. Magnetic particle inspection is particularly well adapted to such inspection in that angles, valves, odd shapes, etc., do not affect its sensitivity.

To summarize:

1. Quality control is just good common sense inspection.
2. It can be as valuable during pipe-line, pump or compressor station construction as it is in other industries.
3. To implement it, we have described magnetic particle inspection by half-wave direct current and its application to pipe-line welds.
4. The analysis of the pipe-line job described proves quality control can help construct a line without defective welds.

Problems Involving the Human Element in Welding

The human element must be considered in our welding problems—the operator, engineer, management and the user

by David P. O'Connor

SINCE the first few years of the 20th Century, the welding industry has developed from a mere novelty to an art and science of today. This development has brought with it a great number of problems to confront the new industry, and the solutions to many of these problems have been found as rapidly as the industry has grown. However, there are problems that have arisen during this period of rapid expansion; problems for which we have yet to find a solution. These are the problems involving the human element in the welding industry.

In the making of a weld there are a number of important factors to consider, some of which are designs, metals used, cost, purpose of the weld and the human element involved. The human element involves everyone concerned, management, the designer or engineer, the welding operator and the user of the welded article. Each of them must be considered an integral part of the welding industry. Men such as these invented every machine and today men operate these machines. It should be remembered that a human being must never be considered secondary to the machine someone

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has invented. He is made up of a nervous system, brain, hopes, fear, ambitions, joys, attitudes and frustrations. All of these show in a person's work and are the basis of the problems involving the human element.

THE OPERATOR

Perhaps one of the greatest problems concerning the human element in welding occurred over 20 years ago. The occasion for this problem was the advent of the coated electrode into the welding industry, which had been using bare electrodes almost exclusively. Research of over 20 years' time had proved to the electrode manufacturer that the use of a coated electrode for welding was far superior to the bare rod then in use. The first people in the welding industry to become acquainted with the coated electrode were mostly engineers who had read or heard of its many possibilities. The problem was for these engineers to convince management, the welding operators and the user of the welded article that the use of the new electrode was highly advantageous.

During the period of time the welding industry was trying out the new electrode, a number of manufacturers were viewing this new rod rather warily. Realizing the coated electrode would make a better and faster weld if used properly, the problem was to find the proper procedure and to teach the operators how to make a sound and efficient weld. The operator, accustomed to welding with bare rod, had been making $1^1/_2$-in. fillet welds or even larger by running a pressure bead, then filling in the whole cross-sectional area in one pass, always welding uphill. With the coated electrode this was impossible. The operators were told to weld downhill with the new rod and to use a series of stringer beads to complete the fillet. The attitude of the welders toward making a weld in such a manner was strictly unfavorable. Then after many hours of hard practice combating the flux and splatter, they turned out a weld that had all the physical properties required even though it did not have a good appearance. After a short period of time the coated electrode was accepted by industry, due not only to its greater speed, lower welding costs and many other possibilities, but to the close cooperation of the engineers, management and the operators, all of whom by their courage and ability were able to overcome one of the larger problems confronting the welding industry at that time.

We are familiar with physical habits to which we automatically respond, such as the welder nodding his head, dropping his hood and striking an arc. In punching a time clock, one removes the time card from one rack, places the time card in the time clock slot to be marked, punches the clock, removes the time card and places it in another rack. All of these are automatic reactions or physical habits acquired over a period of time. An attitude is a mental habit or reaction and can be defined as a habitual way of thinking with regard to a particular individual or situation. Everyone has his own viewpoint that will affect his outlook on the situation. Only by changing his attitude was the welder able to adjust himself to the changing conditions.

THE ENGINEER

Today, however, we still have many large problems involving the human element in welding. Many of the engineers in welding today majored in other mechanical fields and are not always what would be considered welding engineers. Unfortunately, there are a number of engineers throughout industry who have never seen fit to keep abreast of the progress made in welding. They still harbor in their minds the design for riveted joints. From a riveted joint to a welded joint there are a number of changes caused by the heat of the weld. In a riveted joint the chemical analysis means little in comparison to the welded joint. When asked to design for welded fabrication they use such symbols or notes as "weld all around" with no regard for the size of the weld, this being left to the shop supervisor or the welding operator. Little or no consideration is given to the reaction of the metals to be heated. An alloy selected for usage because of its physical advantages may not be weldable due to its chemical analysis. What are the operating temperatures? Are they suitable for welding? These engineers in welding are faced with problems of research, design application, materials involved, cost and other factors, none of which can be passed over lightly because they should not take chances of having failures or rejections, yet they make no effort to avail themselves of the many techniques developed in the welding industry and which are theirs for the asking

Let us now consider the welding operator, another very vital human factor involved in the making of a weld, for it is by coordination of his hand and brain that the actual weld is made. The question arises, "What is the effect of his thoughts on his ability to make a sound weld?" The welder of over 20 years ago was against the radical change of both electrodes and procedure. It disturbed him when he was not able to make a sound and good-appearing weld. He felt his future was in jeopardy, not only from his inability to make a good weld, but from the increased speed of welding with the coated electrode. There was the fear that the increased speed of welding from 25 to 50% would soon force him out of employment. A similar resentment was felt against the automatic or submerged-arc-welding machines which were being used more widely at this same time. He had a natural resentment against any sudden changes.

A recording voltmeter is a useful instrument for many reasons. It records the variation in voltage across the arc, the length of time involved in consuming the electrode and the number of electrodes used over a period of time. Let us pause to consider the welding operator's reaction to this instrument, if the instrument and its operations have not been explained to him. He may feel that the recording voltmeter will disclose some fault in his technique that he is unaware of, or after examining the chart he finds the instrument records not only

the voltage variation across the arc, but also the time involved in melting each electrode and elapsed time for making the weld. He may then have the attitude that this instrument is a sort of stop watch or an electric meter that watches his every move. Surely, this is a poor attitude to acquire.

MANAGEMENT

Management problems concerning the human element are quite numerous. They involve such things as satisfactory working conditions which include wages, the plant itself, ventilation, lighting, ease of handling materials, safety of personnel and, among other things, a good human relations policy. A policy which will educate the employee to the fact that one of the reasons for the use of the previously mentioned recording voltmeter is that the welding operator's health is being considered, for the recorder will readily show when fatigue has affected the operator and whether or not he needs a relief, or if a less laborious method can be devised for doing the work. Fatigue of the welder is a problem, particularly in the welding of high-pressure piping and vessels that require preheating, postheating and stress relieving. In the welding of such piping or vessels it is possible for a fatigue welder to make a poor weld. If on inspection it becomes necessary to remove the weld metal and reweld the seam or joint, the cost and the time consumed readily prove the seriousness of the problem of personnel fatigue. The choosing of supervisory employees is a most difficult problem for management. To find supervisors who can understand people, get along with them and inspire them to greater efforts is a tremendous task. While addressing a health conference several weeks ago, Dr. Sidney A. Portis of Beverly Hills said, "It's not what you eat but what's eating you that gives you that stomach ulcer." Also, a nagging boss is one of the most frequent causes. Dr. Portis explained that a supervisory employee often projects his difficulties onto his fellow workers; they in turn become disturbed, production is impaired and it becomes a vicious circle. The following case will illustrate. A certain supervisor was especially irritable on almost every Friday of the week. Investigation revealed that Thursday night was his lodge night. After lodge a group of members including this supervisor always played poker. Invariably he lost not only his sleep but a considerable sum of money. The combination of his two losses was the cause of his irritation on Friday. It is really difficult to find a supervisor who is not easily frustrated and can readily change his attitude toward certain situations. Management is faced with the greatest of all problems inasmuch as people's feelings are anything but precise and scientific and no two people have the same physical and mental reaction to any occurrence.

At this point we of the AMERICAN WELDING SOCIETY may ask ourselves what we can do to help solve some of these problems of the people who are the human element of the welding industry. We, as members of the SOCIETY, can do our part by introducing the SOCIETY to the technical people and engineers; to have them take an active part in the SOCIETY and to receive the benefits and accumulated knowledge of over 30 years in welding research, which is available to every member. We can prove to the operators and the employees that they should become members of our SOCIETY because through the SOCIETY's efforts, welding has progressed from a novelty of 40 years ago to a necessity of today, and it is their means of livelihood; for only by their cooperation and participation can we hope to solve some of the problems of human relations. We must teach the operator and other personnel involved that by the use of faster and better methods of welding we are not forcing anyone out of work but are actually creating more jobs and more work for industry as a whole. We can show management that by the use of welding, a better product can be developed at a lower cost; that by quality as well as quantity control, a good weld will be made every time.

STUDENTS

There is another group to whom we should give considerable thought and some assistance at this time. This group consists of the students of today—the man power of tomorrow. Welding should be introduced to the schools of the country now, so that the students of today can become familiar with the many phases of this new industry. This early training in welding may be instrumental in the students' choice of a profession, and in their desire to seek a place in the welding industry they will demand of the colleges and universities a recognized course in welding engineering. This is one of our greater problems of today, introducing welding as an art and science to the educational system of America. The problems concerning the human element are really problems of human relations. We of the AMERICAN WELDING SOCIETY may give thought to the words of Frederick J. Bell, Director of Human Relations of the McCormick Co., Inc., of Baltimore, when addressing a national group of business men in Los Angeles a short time ago," Human relations is the hub of the managerial wheel. The spokes of finance, sales, production, research, the movement of the wheels itself, are controlled by the strength of this central core of human relations."

As members of the AMERICAN WELDING SOCIETY it is our obligation to extend our efforts, not by force but by tolerance, to sell, persuade and educate those who make up the spokes of the aforementioned wheel in many ways of human relations. We have the opportunity, the responsibility and the duty of proving to everyone that we are the foremost outstanding technical society in the world today by solving many of these problems in human engineering.

Joining Aluminum to Other Metals

Methods of joining aluminum to other metals and materials by fusion welding, pressure welding, brazing, soldering, diffusion welding and resin bonding

by Mike A. Miller

Abstract

Aluminum can be joined to a large number of other metals by various methods. The joining method chosen will depend on the metal to be joined to aluminum, the design of the parts, the permissible temperatures of joining and on the service requirements of the completed assembly. Arc, resistance and pressure welding; brazing; hard and soft soldering; resin bonding and certain specialized techniques may be employed to join aluminum to other metals and materials. Hard soldering with zinc or zinc-base alloys shows considerable promise for joining ferrous and copper alloys to aluminum. Transition joints, consisting of a short section of aluminum-coated steel tube brazed or welded to aluminum at one end with aluminum welding or brazing alloy, and silver or copper alloy brazed to copper or brass at the other end, should find many applications.

INTRODUCTION

THIS paper discusses and illustrates methods of joining aluminum to other metals and materials. The various fusion processes, such as welding, brazing and soldering, will be discussed first, followed by the various nonfusion methods such as diffusion welding, pressure welding and resin bonding. The various joining processes, as applied to the joining of aluminum to other metals and materials, can be considered in four categories, namely (*a*) those which have given satisfactory experience and are relatively simple to carry out or both, (*b*) those with which there has been limited experience but which are possible to carry out, (*c*) those processes which are not recommended, at the present stage of our knowledge, because of metallurgical, chemical or other interfering factors and (*d*) such combinations of process and metal on which no experience is available at this time. Figure 1 shows these relationships between joining processes and metals or materials to be joined to aluminum. Appropriate sections of the paper may be consulted for details on processes of interest to the reader.

Attention is called to the fact that in many cases special pretreatments of the aluminum, the material to be joined to aluminum, or both, are required with a given joining process. Such pretreatments are discussed in the corresponding sections of this article.

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FUSION METHODS

Welding

Torch Welding. Metallurgically, it would appear impracticable to join aluminum to ferrous or cuprous alloys by a welding technique, since it is known that brittle aluminum-iron and aluminum-copper compounds will form. This is certainly the case under ordinary circumstances. For this reason, direct torch welds of aluminum to copper or brass are not strong in the normal sense but develop better strengths if the copper parts are first precoated with solders or silver brazing alloys, prior to welding with aluminum-base filler wire. These pretreatments result in better wettability and a shorter time at temperature, and as a consequence, less brittle phases are formed.[1] Even better ductility in aluminum to copper torch welds, with aluminum-base filler wire, can be obtained by mixing the welding flux with a fairly large amount of a cadmium halide or cadmium metal powder and then welding in the normal manner.[2] Precautions should be taken to prevent inhalation of cadmium-bearing fumes. However, the joints cannot be considered ductile in the usual sense but this may be of little consequence for specific applications, such as certain electrical joints.

In the case of ferrous and nickel-base metals, somewhat the same situation exists as with copper alloys, namely, welded joints are difficult to make and are brittle. Pretinning the steel with solder or pure zinc improves the ease of torch welding. In addition, the brittleness can be somewhat minimized by the welder by favoring the metal prone to produce the least brittle phase, i.e., the aluminum. Welds of aluminum to magnesium are extremely brittle and are not recommended. Since a flux is used in torch welding, porous materials, such as certain sintered products, should not be torch welded to aluminum.

Arc Welding. Somewhat the same observations which have been made concerning torch welding apply to arc welding. One major difference between torch and arc welding is the shorter time at temperature in the case of the latter, and this, of course, decreases diffusion

Joining Process \ Material Joined to Al	Ferrous Alloys	Copper Alloys	Nickel Alloys	Magnesium Alloys	Silver Alloys	Precious Metals	Zinc Alloys	Lead Alloys	Tin Alloys	Com'l Electroplates or Hot Dip Coatings	Sintered Graphite Bronze	Titanium	Tungsten	Ceramics, Glass, etc	Plastics, Rubber, Wood, etc
Torch Welding	X	X	X	O							O				
Arc Welding	X	X	X	O									X		
Flash Welding	O		O	O											
Resistance Welding	X	O		O											
Brazing		X	X	O						X	O	X		X	
Transition Joints	X	X	X									X			
Hard Soldering			X	X	X		X			X	O	X		X	
Soft Soldering				X							O	X		X	
Diffusion Welding			X			X									
Pressure Welding			X		X	X		X	X						
Resin Bonding			X		X	X	X		X	X	X		X		

Legend

- Satisfactory Experience or Quite Easy
- X — Limited Experience but Possible
- O — Not Recommended
- No Experience

Fig. 1 Summary of major processes for joining aluminum to other metals and materials

and minimizes brittle-phase formation. Ordinary arc-welding processes do not look encouraging, but satisfactory joints have been made between aluminum and aluminum-coated steel by argon-shielded tungsten-arc welding in such a way that the arc favors the aluminum and permits wetting without excessive brittle phase formation. If the coated steel part is supplied too much heat, the aluminum coating is lost by diffusion and a joint cannot be effected.

For making electrical connections in small diameter wires, the possibilities of a special arc-welding technique look interesting. This procedure has been used to join aluminum to copper for electrical applications. Inherently, alloying of copper and aluminum results in a brittle combination, as pointed out in the preceding section and, as a consequence, the resulting welds must be well protected mechanically. A more ductile joint is obtained when the percentage of copper in the weld bead is kept as low as possible. This may be accomplished by using an aluminum sleeve or wire-wrap when joining this combination so as to provide an excess of aluminum in the weld bead. Using a special d-c arc-welding torch with a replaceable carbon electrode, it was found that aluminum could be readily welded in an air atmosphere to copper, brass, iron, steel, Nichrome, Chromel, Alumel, Constantan and tungsten.[3] Some aluminum to copper joints in electrical conductor material, made by this procedure, are shown in Fig. 2.

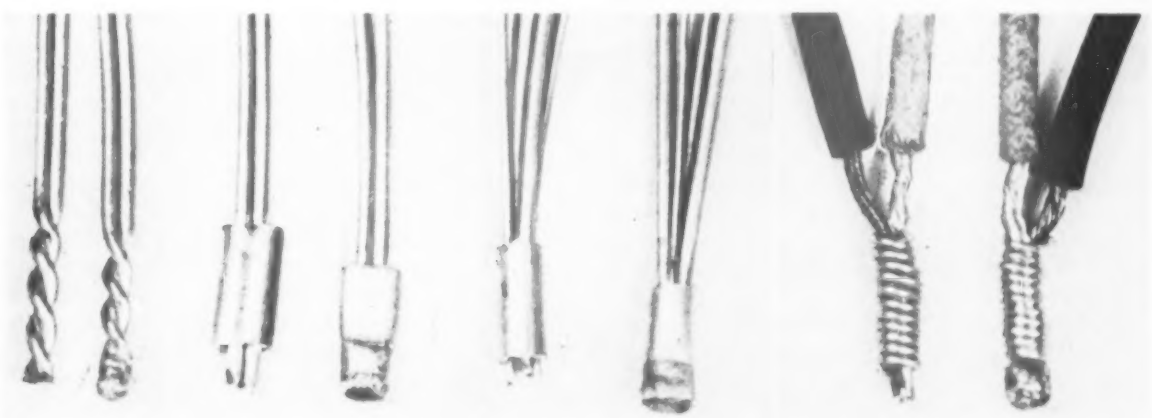


Fig. 2 Various types of wire to wire joints, before and after welding with a special d-c arc-welding torch, illustrating several methods of assembly designed to protect the joint mechanically

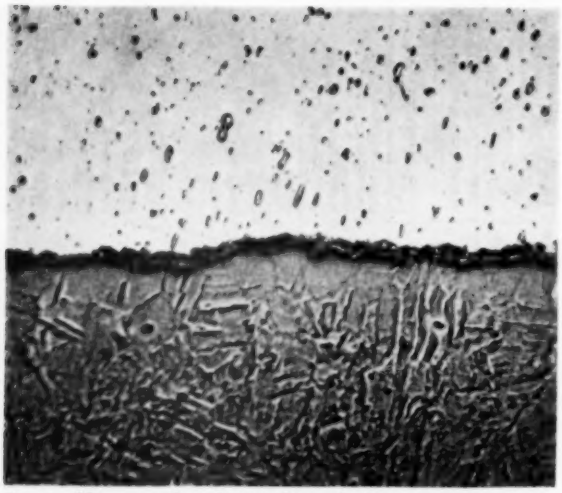


Fig. 3 Micrograph at 500 × through the interface of flash-welded aluminum (top) and copper (bottom) tube. Note very small amount of residual aluminum-copper compounds at the interface. Keller's etch

Flash Welding. Copper may be readily flash welded to aluminum and such joints in tubing have been in use for many years in the manufacture of refrigerators. Figure 3 is a typical section through a flash-welded joint between aluminum tube and copper tube. In this type of joint, it is necessary to force out the low melting, brittle constituents during the upsetting portion of the cycle, in order to render the resulting joints ductile. Aluminum shapes other than tube, such as wires, round rods, extruded shapes and sheets of aluminum, have been flash welded to similar shapes of copper. Such joints have found use in the substitution of aluminum for copper coils on heavy, high-speed rotating electrical equipment, moving coils of electrical measuring instruments and transition joints in tubing between aluminum refrigerator evaporators or condensers and copper parts of compressors.

By careful adjustment of welding conditions copper base alloys may be joined to aluminum by flash welding. However, experience has shown that, although copper and brass can be made to produce satisfactory joints, steel produces quite brittle joints by this procedure. This is because aluminum-copper constituents are molten during the welding cycle and readily forced out of the joint, whereas solid iron-aluminum constituents cannot be eliminated from the fusion zone. Aluminum to steel joints can, however, be made by using an intermediate copper section, which can be flash welded to aluminum at one end and to steel at the other. The use of such transition joints will be discussed in more detail in a later section.

Resistance Welding. It is well known that all the commercial aluminum alloys can be spot and seam welded, provided the thicknesses involved are not too great. Spot or seam welding aluminum and its alloys to a dissimilar metal or alloy is, however, very difficult and procedures involving bare ferrous metals have produced inconsistent results. Hess and Nippes[4] have had some success with an intermediate metal plating layer to effect a satisfactory bond between aluminum and aircraft-type steels and found that the most promising method was to electroplate 0.25 mil of silver on the steel parts and to spot or seam weld after this, employing suitably cleaned aluminum parts. Silver electroplates produced high-strength, ductile welds independent of welding current and electroplate thickness over a wide range. Other electroplates on steel were less satisfactory than silver in spot welding to aluminum. It is interesting to note that aluminum brazing sheet produced better spot welds to steel than did 3S alloy, probably because the brazing alloy coating melted at a lower temperature, thus permitting lower heat input.

Resistance welding of aluminum to copper or copper alloys is not practical because of the extreme brittleness of the joints.

Brazing

Aluminum brazing techniques may be used for joining aluminum to other metals, particularly the ferrous alloys, providing the latter are given special surface pretreatments. Several examples will serve to illustrate the procedures which appear to be practicable.

Aluminum to Copper. It is difficult to braze copper and its alloys to aluminum because of the low melting temperature of the aluminum-copper eutectic composition and its extreme brittleness. However, by rapidly heating and cooling, reasonably ductile joints have been obtained with aluminum brazing alloy filler metal and aluminum brazing fluxes for such applications as copper inserts in aluminum castings. Somewhat better joints can be obtained with aluminum brazing alloys as filler by first tinning the copper surfaces with solders or silver brazing alloys. This is primarily the consequence of the rapidity of wetting and shorter time at temperature. Joints between aluminum and copper can also be made by using silver or silver-base alloy filler material instead of aluminum brazing alloys, providing the joint is made rapidly. By heating such a joint with aluminum brazing flux very rapidly, with a torch for example, diffusion and alloying take place so that a molten aluminum-silver-copper alloy forms and effects a joint. Cooling of such joints must be rapid in order to prevent complete melting and collapse of the components at the joint.

Aluminum to Ferrous Metals. In general, it is difficult to braze aluminum to bare steel because of oxidation of the steel when torch or furnace brazing, or during preheating in an air furnace prior to dip brazing. In the case of dip brazing, oxidation may be obviated by dipping unpreheated parts into molten flux, but this procedure has limited application because of warpage and misalignment of parts. A process has recently been described[5] for simultaneously aluminum coating sand-blasted steel tube, and furnace brazing it to aluminum sheet, by using a special procedure.

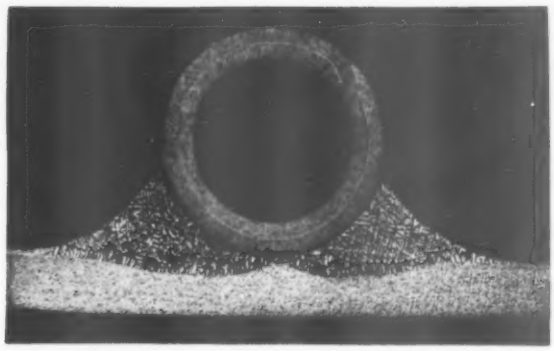


Fig. 4A Micrograph at 10 × through a furnace-brazed joint between "Bundy" steel tube (top) and aluminum brazing sheet (bottom). Keller's etch

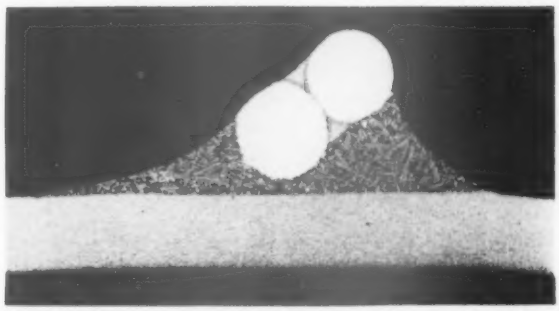


Fig. 4B Micrograph at 10 × through a torch-brazed joint between aluminum-coated steel wires (top) and 3S aluminum made with an aluminum brazing alloy wire (bottom) and flux. Keller's etch

Electroplated steels can be brazed to aluminum more readily than can bare steel. Iron, copper, nickel or zinc electroplates and zinc or aluminum hot-dip coatings have been used to promote wetting of the steel. An example of copper as a coating material on steel is illustrated in Fig. 4*A*, which is a section through a furnace-brazed joint between Bundy copper-brazed tubing and aluminum brazing sheet. Zinc electroplates have also been used to good advantage. For example, dip-brazed lap joints, made by slipping 1.30-in. diam zinc-plated mild steel tubes into 53S alloy tubes, using about an inch lap and aluminum brazing alloy wire, required a load of 30,000 lb to push the steel tube through the aluminum alloy tube. The furnace brazing of plated steel liners or sleeves in brazed aluminum cylinder blocks, as well as steel valve seats in brazed aluminum cylinder heads, has recently been considered to be practical.[6]

Probably the most satisfactory surface preparation for ferrous parts, prior to brazing them to aluminum, is to coat them with aluminum or an aluminum alloy. There are a number of products, processes and techniques that can be used for this purpose.[7] It should be noted that in all cases more or less brittle iron-aluminum compounds are formed at the interface. When a rapid method of brazing can be used, so as not to increase the thickness of the brittle compound layer, aluminum brazing is probably the most practical answer to the problem of durable aluminum to steel applications. The type of joint and the conditions of its use are, of course, to be considered in view of the difference in thermal expansion between aluminum and ferrous materials.

Aluminum-coated steels may readily be torch brazed to aluminum, using available aluminum brazing alloys and fluxes. The procedure is the same as would be used to braze aluminum to aluminum, except that rapidity—to minimize brittle phase formation—should be emphasized. Figure 4*B* shows a section through a torch-brazed joint between aluminum-coated steel wires and aluminum sheet. This joint was made by a normal aluminum torch brazing technique with aluminum brazing alloy and flux. When a rapid preheat can be used dip brazing of aluminum-coated steel to aluminum can produce excellent joints. Tube to tube joints, with a nominal clearance of about 0.010 in. and laps varying from 0.50 to 2.50 in., have developed shear strengths of 10,000 to 15,000 psi.

Since a flux is used in the aluminum brazing process, it is important that all flux residues be removed after brazing. Where this is impossible, as in certain complex or specialized applications, a three-step procedure can sometimes be employed. For example, the steel parts can be hot dipped in aluminum, either completely

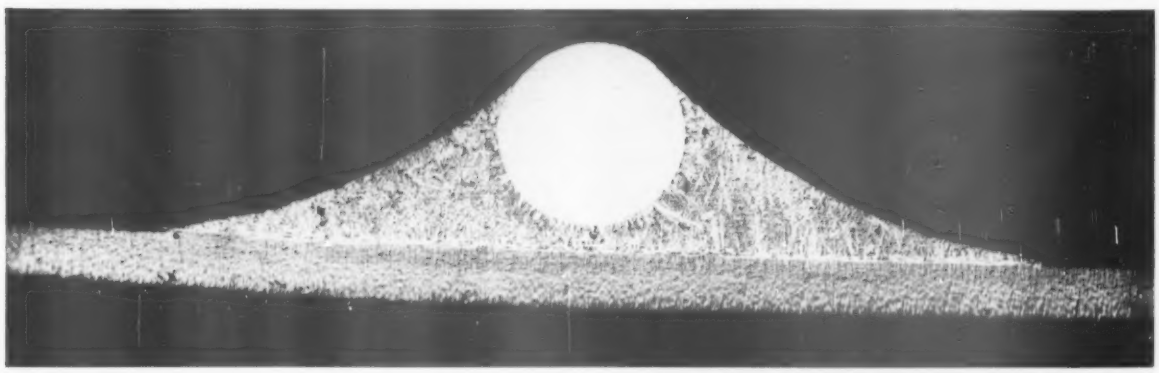


Fig. 4C Micrograph at 20 × through a torch-brazed joint between aluminum wire (top) and aluminum-coated titanium (bottom) made with aluminum brazing alloy and brazing flux. Keller's etch

or locally, followed by brazing an aluminum section to the aluminum-coated steel. The subassembly should then be thoroughly cleaned to remove all flux residues, after which the aluminum section can be welded to the aluminum parts of the final assembly by argon-shielded tungsten-arc or consumable electrode methods. An example will serve to illustrate this procedure. A section of steel tube was hot-dip coated with aluminum at one end and the aluminum-coated end dip brazed to a section of aluminum tube. After thoroughly cleaning the brazed subassembly to remove residual brazing flux, the aluminum tube portion was welded to an aluminum container, which had been furnace brazed and cleaned in separate operations, by means of the argon-shielded tungsten-arc process. Tests showed that the completed assembly was vacuum tight. Alternately, some types of joints can be made by argon-shielded tungsten-arc welding the aluminum part to the aluminum-coated steel part, as mentioned under arc welding, thus eliminating the necessity for flux removal.

Aluminum to Other Metals. Nickel, Inconel and Monel have been experimentally brazed to aluminum and are no more difficult to braze, under proper conditions, than are ferrous parts. Titanium may be hot-dip coated with aluminum, after which it can be brazed to aluminum with aluminum brazing alloys. Figure 4*C*, for example, shows a section through a torch-brazed joint between aluminum wire and aluminum-coated titanium sheet. The interface of the titanium and the aluminum brazing alloy, shown at 500 × in Fig. 4*D*, is extremely thin and uniform and only a minimum of alloying has taken place.

Magnesium alloys, of course, should not be brazed to aluminum because of the extremely brittle aluminum-magnesium phases that form during brazing.

Transition Joints

In cases where for metallurgical or other reasons it is impractical to join aluminum to another metal directly, an intermediate or transition metal section can sometimes be used to advantage to accomplish the desired result. The use of a copper transition section between aluminum and steel, assembled by flash welding, has been mentioned in a preceding section. Where flash welding of the copper and steel portions is not possible, as for example in field erection of assemblies, this joint could in some cases be made by silver alloy brazing.

For certain applications, a steel transition section may be used between aluminum and copper parts. Such a joint is shown in Fig. 5 just below the flash-welded joint. In making such a joint, the steel section should be first dip coated with aluminum at one end, the coated end brazed, or in some cases welded, to the

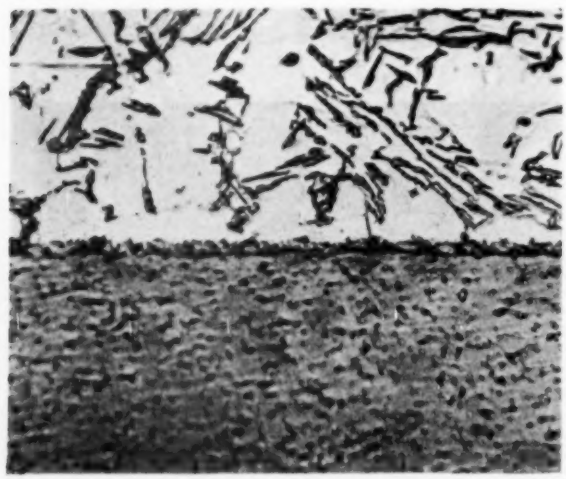


Fig. 4D Interface of titanium and aluminum brazing alloy at 500 ×. Keller's etch

Fig. 5 Various methods of making joints between aluminum and copper tube: flash welding, brazing, hard soldering, soft soldering, pressure welding and resin bonding

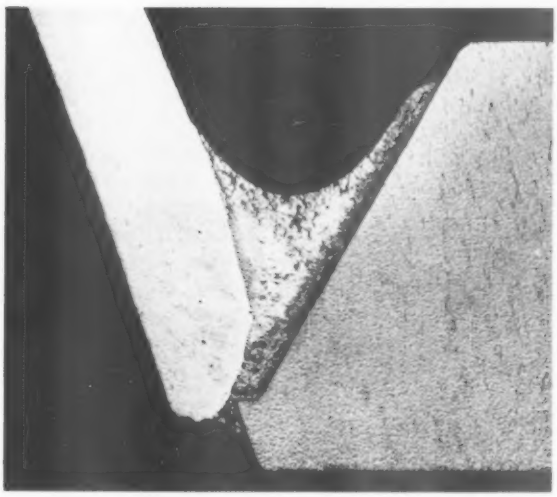


Fig. 6A Micrograph at 10 × through the interface of aluminum container wall (left) and nitralloy steel (right), zinc soldered in a nonoxidizing atmosphere with a salt-type soldering flux

aluminum section by aluminum brazing or welding techniques and the bare end silver or copper alloy brazed to the copper section. Such joints are useful for assembly of parts in which the copper portion cannot be joined to aluminum by flash welding because of size, shape or position.

Soldering

Hard Soldering. Aluminum can be joined to a number of other metals with pure zinc or zinc-base alloys. Since zinc is a fillet-former, it is generally desirable to design joints between aluminum and other metals with taper fits for tube, or line contacts for other parts. The use of a tapered joint for zinc soldering a Nitralloy steel fitting to an aluminum container is illustrated in Fig. 6A. In this case, the joint was furnace soldered in a nonoxidizing atmosphere at 800° F, using a pure zinc wire ring as filler. The steel parts were grit blasted and a methanol suspension of an aluminum brazing flux applied to the joint prior to soldering.

Copper or brass parts need only be cleaned in any convenient manner. Heating may be in a furnace or by means of torch. Pure zinc, zinc-aluminum, zinc-copper and zinc-tin alloys may be used as filler; the last named has a poorer resistance to corrosion than the others but can be applied at lower temperatures. Figure 6*B* shows the interface of an aluminum and 70–30 brass joint made in a furnace with a 70% zinc – 30% tin solder and a salt-type flux. The third joint in Fig. 5 shows an aluminum and copper tube hard soldered with pure zinc.

In addition to the metals described in the preceding, nickel, magnesium, silver and zinc have been experimentally hard soldered to aluminum with zinc-base alloys.

Fig. 6B Micrograph at 500 × through interface of 3S aluminum (top) and brass (bottom) joint, made with a zinc-base solder (darker band in middle) in an air furnace with a salt-type soldering flux. Note diffusion of solder into brass and compound formation

Soft Soldering. Aluminum can be soft soldered, directly or indirectly, to practically all commercial metals and alloys. In the absence of fluxes to remove the oxide film from aluminum, rub-tinning or other mechanical means is required to remove the oxide film and effect a "tinned" surface. Many commercial soldering fluxes for aluminum are salt-type fluxes, generally based on zinc chloride or other heavy metal halides, together with smaller amounts of other chlorides and fluorides. Such chloride fluxes are very effective on aluminum but the residues are generally hygroscopic and can accelerate corrosion of aluminum, particularly when in contact with a dissimilar metal. It is very important, therefore, that all such flux residues be removed. This may be difficult to do for certain kinds of joints, for example, stranded cable-terminal joints, and in such cases it would be desirable to use a chloride-free soldering flux. One such flux[5] is an organic-base material in the form of a viscous liquid. This material contains no chlorides and is not corrosive to aluminum. Residues of this flux are virtually without effect as far as acceleration of corrosion is concerned.

The wide range of metals and alloys that had been joined to aluminum by soft soldering, using the above chloride-free soldering flux, are illustrated in Fig. 7. In this figure, the indicated metal or alloy is in each case soldered to an aluminum wire. The metals criss-cross the periodic table from aluminum to platinum and from nickel to gold. Stainless steels, Alnico magnet alloy, Kovar, cast iron, etc., are all readily solderable. The only metals found not to be readily solderable with this type of flux are magnesium and the so-called refractory metals—titanium, zirconium, columbium, tantalum, molybdenum and tungsten. However, such metals can be soldered to aluminum after electroplating with a solderable metal, by tinning the surface with silver alloy solder, or other special procedures. For example, titanium that has been hot-dip coated with aluminum can readily be soldered to aluminum with an

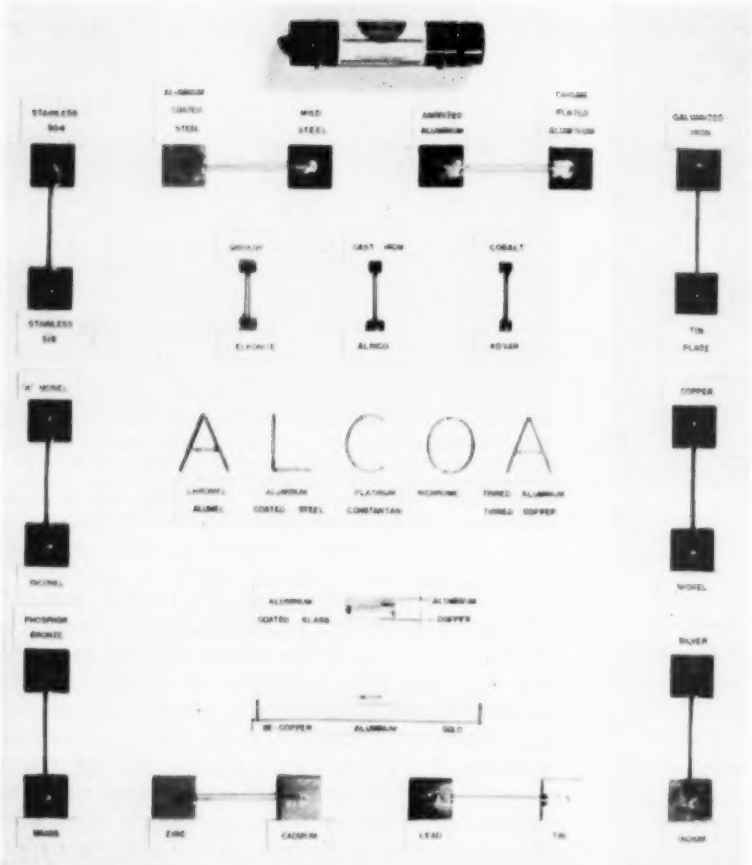


Fig. 7 Soldered joints of aluminum wires to various metals and alloys made with chloride-free soldering flux

aluminum solder and a chloride-free flux. Tin- or solder-coated aluminum wires can, of course, be soldered with rosin-cored lead-tin solders.

NONFUSION METHODS

Diffusion Welding

The combination diffusion and pressure welding of dissimilar aluminum alloys has recently been discussed in THE WELDING JOURNAL and metallographic evidence was given to show the trans-interface migration of alloy constituents.[9] A similar procedure may be employed for the joining of aluminum to other metals, using silver electroplates on the parts, with the advantage that much lower deformations are required to produce satisfactory joints than are possible with conventional pressure welding techniques. Because of this, the term "diffusion welding," formerly referred to as "diffusion bonding," is suggested for this procedure. In carrying out the process, the silver-plated parts are simply pressed together at rather low pressures and at temperatures up to 600° F for a period of time. The recrystallization temperature of cold-worked silver is about 390° F, and it has been found that adherent welds cannot be made below this temperature, even at pressures as high as 45,000 psi.[10] Thus, recrystallization must be an important factor in this welding process.[11] For silver electroplates, a suitable temperature for pressure diffusion welding is about 600° F.

Figure 8A illustrates a case where only the aluminum

Fig. 8A Micrograph at 500 × through the interface of silver-copper contact alloy (top) and silver-plated ALCOA 61S-T6 aluminum (bottom) joint made by heating for 30 min at 600 F and 13,700 psi. Total deformation less than 1%. Dark line is residual silver plating

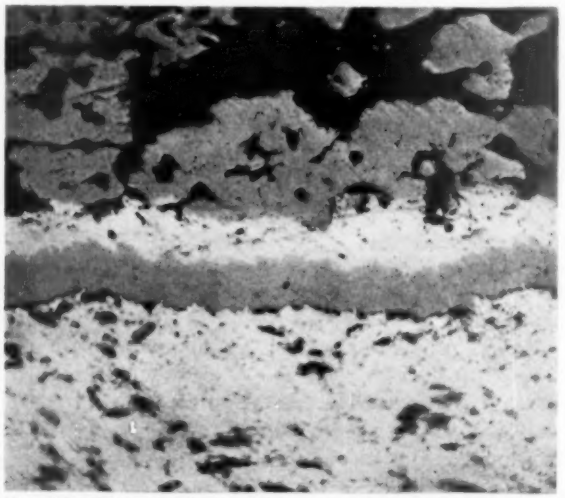


Fig. 8B Micrograph at 500 × through the interface of silver-plated sintered graphite-bronze bearing (top) and silver-plated ALCOA 3S aluminum joint (bottom) (0.0002-in. silver on each surface) made by heating for 1 hr at 600° F and 1500 psi. Note interdiffusion of silver (middle layer)

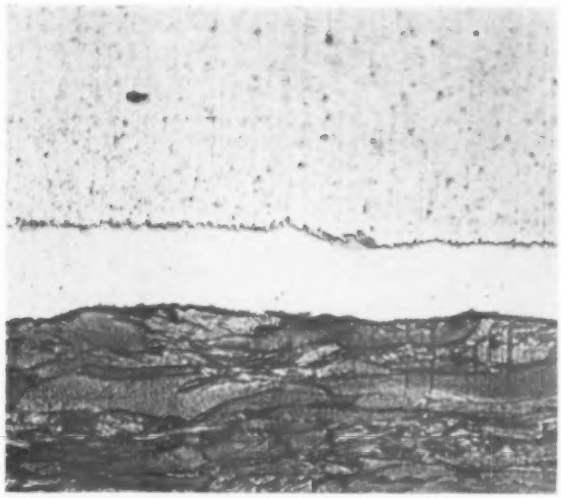


Fig. 9A Micrograph at 500 × through interface of silver-plated high purity aluminum (top) and silver-plated mild steel joint (bottom) made by preheating to 450° F and hot rolling with 50% reduction on the first pass, followed by rolling to 0.064 in. Note that the two silver layers have merged into one (middle layer)

Fig. 9B Micrograph at 500 × through interface of silver-plated copper (top) and silver-plated aluminum joint (bottom) made by preheating to 500° F and hot rolling with a 40% reduction on the first pass followed by rolling to 0.050 in. The self-diffused silver layer is in the center. As-polished

surface needs to be electroplated with silver. This figure shows the interface at 500 × of a joint between silver-plated 618-T6 alloy and a sintered silver-copper contactor alloy made at 600° F and 13,700 psi, using a total time of 30 min and a total deformation of less than 1%. For joining other metals or combinations of metals to aluminum, it may be necessary to electroplate both surfaces. An unusual case may be illustrated by Fig. 8*B* which shows the interface, at 500 ×, of a sintered graphite-bronze disc and aluminum joint. The graphite-bronze and the 3S aluminum were each electroplated with about 0.2 mil of silver and pressed at 1500 psi for 1 hr at 600° F, in an ordinary hydraulic press containing electrically heated platens.

Rolling of component parts, naturally, is analogous in many respects to pressing, except that somewhat greater deformations may be required. Thus, silver-plated aluminum may be joined to silver-plated steel or copper by preheating the component parts to about 750° F and rolling them together with about a 50% reduction in area on the first pass. Basically, rolling parts together is no different than pressing the same components, the idea being to join aluminum to another metal.[12] Rolled parts, in general, have a more limited shape factor than do pressed parts. This technique, however, can produce composite parts that either can be used in the as-fabricated form or can subsequently be joined to other metals. Figures 9*A* and 9*B*, respectively, show the interfaces of aluminum and steel and aluminum and copper joints, prepared by diffusion welding with the rolling technique.

Pressure Welding

Pressure welding is the formation of a solid-phase weld between metallic materials by the application of a deforming pressure at any temperature below the melting point of the components. Temperature, pressure and time are the important factors in pressure welding any metal, since they determine the amount of deformation. All of these factors influence diffusion,[9] recrystallization[9,11] and related phenomena. In contrast to diffusion welding, pressure welding generally requires appreciable deformations to effect satisfactory bonds, the deformation generally decreasing with increasing temperature.

The deformation required for satisfactory pressure welding at room temperature varies with the metals being welded. Some optimum values are 20% deformation for scratch-brushed gold, 60% for aluminum and 80% for iron. It is apparent that controlled deformation must be empolyed in pressure welding dissimilar metals. An example will serve to illustrate this. For "maltese cross" indentation type of lap joints, pressing aluminum to aluminum at 6000 lb gave joints with about 100% efficiency, whereas aluminum to copper joints under the same conditions gave a joint efficiency of only 70%, based on the strength of the aluminum. In contrast to this a pressure of 10,000 lb gave only 60% efficiency in copper to copper joints of the same type.[9] Figure 10*A* is a photomicrograph, at 500 ×, through a typical aluminum to copper joint made in 0.125-in. diam wire at room temperature and a pressure of 15,000 lb.

For hot-pressure butt welding of aluminum to copper, a modification of the simple butt joint has recently been suggested. The aluminum portion is heated to about 1125° F while in the die, and the parts pressed together with a hammer blow, forcing the unheated copper into the aluminum to give a slight "flash," corresponding to the contour of the die cavity.[13]

Three different methods have been proposed for hot-pressure welding a number of aluminum alloys to steel, namely, a twisting procedure, a hot-pressing procedure and a shearing procedure.[14] It was found that, regardless of the initial bonding technique, the strengths of as-bonded assemblies could be increased as much as

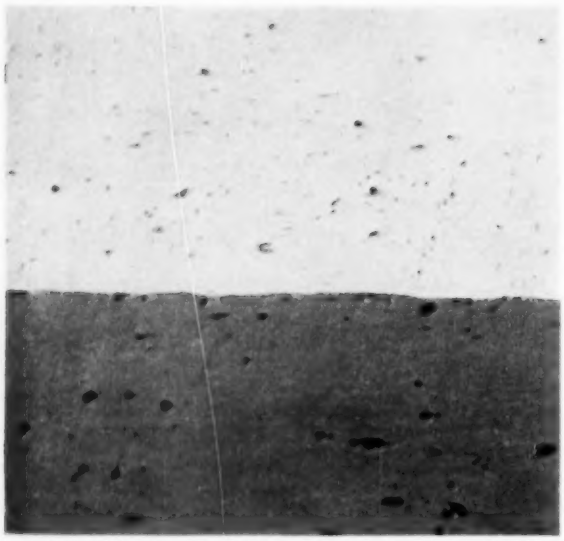


Fig. 10A Micrograph at 500× of pressure weld in 0.125-in. diam ALCOA 28-H18 wire (top) to 0.125-in. diam annealed copper wire (bottom) made at room temperature and a welding pressure of 15,000 lb. As-polished

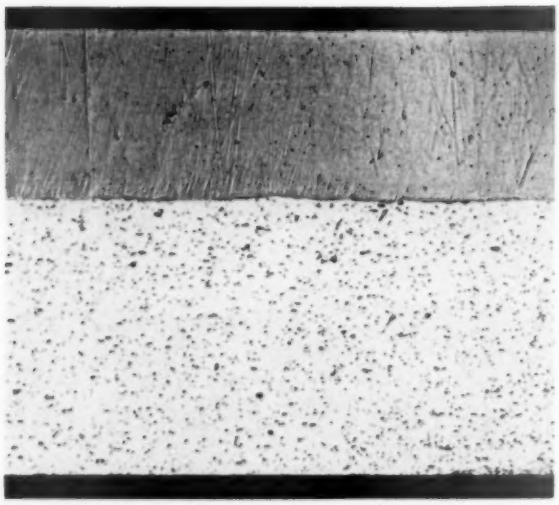


Fig. 10B Micrograph at 250 × through 0.010-in. copper-clad (top) aluminum (bottom). After cold rolling from 0.125 in. Note absence of interfacial alloy layer. Keller's etch

100% by a subsequent heat treatment. Previous work[15] had shown that the strength of aluminum to stainless steel bonds could be substantially improved by heat treatment after bonding. In addition to copper and steel, nickel, zinc and lead have been pressure welded to aluminum. With proper conditions, probably any metal can be pressure welded to aluminum.

There has been a considerable interest in copper-clad aluminum and a number of methods based on rolling techniques have been suggested or are in commercial use.[16] Properly fabricated sheet has an interface metallurgically which is no different than a pressure weld, as shown by the photomicrograph in Fig. 10*B*. It is virtually impossible to weld silver alloy braze or zinc solder this material, because of the formation of a brittle aluminum-copper alloy interface. It may readily be soft soldered or pressure welded, however. In addition to copper-clad aluminum sheet, other combinations are available, such as copper-clad aluminum wire and tube; gold- or silver-clad sheet, wire and tube; and brass-clad sheet. Tin- and zinc-clad aluminum have recently become production items for purposes of soft soldering, and silver-clad aluminum for electrical contacts, wave guides, hollow ware, etc. Tri-metal combinations include aluminum clad with silver on one side and copper on the other and steel with aluminum on one side and nickel on the other.

Resin Bonding

Resin bonding may be broadly defined as a process of making metal to metal or metal to nonmetal joints by means of organic or resinous cements, generally with the application of heat and pressure. Resin bonding may be carried out in the temperature range of room temperature to about 500° F. A large number of adhesives, both cold-setting and hot-setting, are commercially available. Resin-bonded joints should be designed to take shear loads, the strength developed being dependent on the adhesive and the length and type of lap joint involved. These adhesives, being organic in nature, cannot be used for elevated temperature service.

A typical example of the use of resin bonding is the joining of steel or copper tube to aluminum tube with a hot-setting adhesive of the epoxy type which requires little or no pressure during bonding. The joint should be designed with a slip fit of generous clearance or, preferably, with a taper fit. The parts should then be heated to about 250° F, the adhesive applied to the mating surfaces, the parts assembled while hot, additional adhesive applied to the joint and the adhesive cured at 465° F for 10 min or at 390° F for 20 min. Some of the epoxy type adhesives are particularly useful for sleeve-type joints in tubes because of their excellent capillarity during the thermoplastic stage. The bottom aluminum to copper tubular joint shown in Fig. 5 was made by this procedure. Aluminum has been resin bonded to a great many types of metals and nonmetals, but suitable adhesives must, of course, be chosen. Among the metals that have been bonded to aluminum are brass, galvanized iron, magnesium, stainless steel, copper, tin plate, lead, etc. Surface preparation, particularly of the aluminum, is very important. As would be expected, certain adhesives give higher strength joints on some metals than others. In fact, some adhesives give no wetting or adhesion on certain metals. Accordingly, in resin bonding dissimilar metals, care should be taken to use an adhesive that gives the optimum strength on both metals.

An interesting application of resin bonding, which involves aluminum to another metal, is an aluminum-backed rotary printing press plate. In this case the bond is between the aluminum backing and the lead

alloy filler for the copper electrotype. Another application in the experimental stages is the bonding of aluminum water pipe to brass fixtures, due care being taken to insure nonmetallic contact between the dissimilar metals.

Miscellaneous Methods

Space does not permit more than a brief mention of specialized methods of joining aluminum to other metals. A few of these techniques should be mentioned, however, since the welding engineer of today is quite conscious of joining in general, and should have alternate techniques in mind when appraising a job. There seems to be the general feeling among the engineers in the field of joining that casting, rolling and chemical methods, among others, are becoming increasingly important in the assembly of a required part. A few examples should serve to illustrate this new thinking.

Hot-dip aluminum coatings on several metals may be used, while still molten, for casting various aluminum alloys directly onto the coated surface. Aluminum may thus be bonded to such aluminum-coated metals as gray, malleable, ductile or nodular irons; austenitic irons; carbon and stainless steels; Inconel and titanium.[17] Applications of the procedure are aircraft cylinders with aluminum fins, gears with steel hubs and aluminum rims, aluminum-finned steel brake drums and steel-backed aluminum bearings. The use of both casting and brazing procedures is illustrated by the manufacture of a 14-in. diam aluminum-finned radiator of an anode for a 4000-w power tube. This radiator consists of a thin steel liner bonded to the inside of an aluminum casting of heavy cross section. The composite tubular section is then furnace brazed at 1075° F to stamped aluminum fins. Finally, the copper anode is soldered inside the steel liner of the finned radiator.

It has been found that silver electroplates on aluminum, less than a tenth of a mil thick, are sufficient to permit instantaneous and complete wetting when the parts are immersed in molten zinc, without the use of a flux. Furthermore, the silver electroplate greatly decreases the tendency of zinc-base alloys to penetrate into the aluminum. This procedure can be used not only for joining aluminum to other metals with zinc or zinc-base alloys, but also for casting zinc on a zinc-coated aluminum surface, while the zinc coating is still molten.

An interesting method, although of problematical general usefulness for aluminum except for parts operating in the complete absence of moisture, has been proposed for joining various metals to aluminum alloys by a combination of electroplating, amalgamation and heating under pressure.[18] For example, in joining aluminum to silver or copper, the aluminum can be silver plated and then the copper or silver and the silver-plated aluminum amalgamated with mercury. The parts can then be assembled and heated under pressure at 400–500° F for a period of time to distill off the major portion of the mercury. Since mercury is known to be a corrosion hazard for aluminum,[19] such a joining method is not recommended except perhaps for special parts operating in the complete absence of moisture.

Brief mention should be made of a few methods of joining aluminum to other materials than metals, particularly since some of these methods are similar to those used in conventional metal-to-metal joining. It is well known that, by the use of certain active metals or their hydrides, it is possible to braze metals to nonmetals. The active metals are titanium, zirconium, columbium and tantalum, and the brazing process must be carried out in vacuum or in an inert gas such as pure argon. Many nonmetallics such as glass, ceramics, diamonds, sapphires, etc., can be joined to various metals and alloys. Aluminum-zirconium and aluminum-silver-zirconium alloys are among those that can be used as filler material. For joining aluminum to nonmetallic materials, a transition type of joint can be used. For example, corundum has been brazed to stainless steel in an argon atmosphere with a silver-zirconium alloy, followed by torch brazing the assembly to aluminum.

Glass can be coated with certain aluminum alloys readily under proper conditions and this can, of course, be used as a means of joining glass to aluminum and other metals by soft soldering. Certain solders, such as those containing tin and indium, can "wet" glass. For example, an alloy of approximately equal amounts of tin and indium can be swabbed on glass heated to an appropriate temperature. Such a coated glass surface has been soldered, with the tin-indium solder, and without flux, to an aluminum surface that has first been pretinned with lead-tin-zinc solder and a chloride-free flux. Such joints have been found to be vacuum tight when carefully made. Aluminum can be soldered to glass following other surface preparations than those already discussed. For example, glass may be sand or grit blasted, and then, with proper preheating, sprayed with copper, silver or even aluminum, and then soft soldering techniques used to solder aluminum or other metals to the sprayed coatings.

By the use of resin bonding, aluminum has been joined to such nonmetallic materials as glass, plastics, rubber, fiber board, plywood, gypsum board and many other materials. A good example of this technique is the aluminum-faced honeycomb panel which is finding wide applications.

SUMMARY

A number of fusion methods are available for joining aluminum to other metals. Of the welding processes, arc and flash welding are of more general usefulness than are torch or resistance welding. Brazing methods, while of limited usefulness in the joining of aluminum to copper and copper-base alloys, except by the use of transition joints, are of considerable usefulness for joining aluminum to ferrous alloys, particularly if the ferrous parts are given a suitable surface preparation, the best of which appears to be an aluminum coating.

A large number of metals and alloys can be joined to aluminum by soldering techniques. Both high-temperature solders, such as pure zinc or zinc-base alloys, and so-called soft solders may be used, the former exhibiting a much better resistance to corrosion than the latter. Casting procedures are coming into wider use, particularly the casting of aluminum onto aluminum-coated steel parts. Procedures are also available for casting lower melting metals, such as zinc, lead, tin, etc., onto aluminum parts. Other specialized techniques are also available.

Many nonfusion methods can be used for joining aluminum to other metals, as well as to nonmetals. For example, silver-plated aluminum may be bonded to pure silver, certain silver alloys and to any metal that can be silver plated, by heating the parts together at 500-600° F for a period of time under pressure; silver readily diffuses across the interface and results in a good joint. This type of joining can be carried out either by pressing or rolling. Pressure welding, either at room or elevated temperature, under conditions to give proper deformation, is becoming increasingly important for joining aluminum to metals such as copper and steel. As with diffusion welding, either pressing or rolling may be used. Besides copper and steel, nickel, zinc, lead, etc., have been welded to aluminum by pressing and gold, silver, brass, tin and zinc, by rolling. Resin bonding, i.e., the use of synthetic resinous adhesives, can be used to join aluminum to practically any metal or nonmetal if the proper adhesive is chosen.

It is apparent that a wide range of methods, giving joints under various conditions and possessing different characteristics, are available for joining aluminum to other materials.

References

1. Holler, H., and Maier, A. F., "Contribution to the Investigations into the Gas Welding of Aluminum with Other Metals," *Autogene Metallbearbeit.*, **28** (12), 177, 179–183, 197 (1935).
2. U. S. Pat. 2,239,018 to Aluminum Company of America.
3. Dixon, C. R., and Dickerson, P. B., "Arc Welding Process for Making Electrical Connections in Small Aluminum Wire," *Automotive Ind.*, **107**, 50–51, 100, 102 (1952).
4. Hess, W. F., and Nippes, E. F., Jr., "A Method for Welding Sheet Aluminum to SAE 4140 Steel," THE WELDING JOURNAL, **25** (3), Research Suppl., 129-s to 148-s (1946).
5. Bregman, A., "Metal Finishing of Household Equipment at Servel's Plant," *Metal Progress*, **59** (6), 646–649 (1951).
6. Dunn, J. H., and White, E. P., "New Applications and Developments in Aluminum Alloys," *SAE Journal*, **60**, 45–51 (1952); *Modern Metals*, **8**, 42–51 (1952).
7. See, for example: (*a*) U. S. Pat. 2,315,725 to G. A. Moeller; (*b*) U. S. Pat. 2,569,097 to General Motors Corp.
8. U. S. Pats. 2,238,068, 2,238,069 and 2,286,298 to Aluminum Company of America.
9. Miller, M. A., and Oyler, G. W., "Pressure Welding Aluminum at Various Temperatures," THE WELDING JOURNAL, **30** (10), Research Suppl. 486-s to 498-s (1951).
10. Butts, A., and Van Duzee, G. R., "Cold Welding of Silver," *Trans. Electrochem. Soc.*, **74**, 327–339 (1938).
11. Parks, J. M., "Recrystallization Welding," THE WELDING JOURNAL, **32** (5), 209-s to 222-s (1953).
12. U. S. Pats. 2,539,246, 2,539,247 and 2,539,248 to P. R. Mallory, and Co.
13. Ger. Pat. 852,490 to W. Hofmann and J. Ruge.
14. Cooke, V. W., and Levy, A., "Solid-Phase Bonding of Aluminum Alloys to Steel," *Jnl. Metals*, **1** (11), 28, 35 (1949).
15. U. S. Pat. 2,171,040 to Aluminum Company of America.
16. See, for example: (*a*) Siegel, S., "Modern Composite Metals," *Jnl. Metals*, **188** (7), 916–920 (1950); (*b*) Ottmar, J., "Composite Metals: A New Key to Design Flexibility," *Product Eng.*, **23**, 153–157 (1952).
17. See, for example: (*a*) U. S. Pat. 2,396,730 to Fairchild Engine and Airplane Corp.; (**b**) Stevens, C. E., Jr., "Bonding of Steel to Cast Aluminum and Uses Thereof," *Metal Progress*, **55** (3), 326–331 (1949).
18. See, for example: (*a*) U. S. Pats. 2,094,448 and 2,094,483 to General Electric Co.; (*b*) Fr. Pat. 943,599.
19. Brown, M. H., Binger, W. W., and Brown, R. H., "Mercury and Its Compounds—A Corrosion Hazard," *Corrosion*, **8** (5), 155–164 (1952).

PRACTICAL WELDER AND DESIGNER

Oil Industry Tries Out Aluminum for Pipe Lines

New welding system installs 40-ft length of pipe every 3 min

FOR any location where transportation is a dominant factor, the light weight of aluminum pipe provides an economic advantage, according to test data accumulated by Reynolds Metals Co. Thus when installing pipe lines through swamps, over mountain ranges, lakes, oceans, and river crossings, it has been demonstrated that aluminum can save money.

Another important advantage of aluminum is its great resistance to corrosion from sour gas and sour crude oil. Recently two aluminum pipe lines totaling 6 miles were installed in the Permian Basin to be used for gathering sour gas. Their cost was competitive with that of steel pipe, and the users obtained the advantage of aluminum's resistance to corrosion while its light weight and ease of installation permitted use of a fast automatic welding system that allowed complete 40-ft lengths of 6-in. pipe to be lined up, welded and lowered in at an average of one every 3 min.

A number of river crossing installations have been made including a 10 1/4-in. diam, 3/16-in. wall gathering line carrying sweet natural gas at pressures up to 250 lb a square inch across the north fork of the Little Colorado River near Bowie, Okla. The river crossing uses eleven 30-ft sections of extruded aluminum pipe with ends beveled 30 deg for welding.

The total span from pier to pier is 318 ft. The aluminum line was welded on a wooden scaffold on Pier No. 1. As each new length of pipe was welded in place, it was pushed ahead 30 ft onto the cable suspension system.

A single 1 1/4-in. steel cable supports the entire pipe system. Aluminum flanges at each end of the crossing are bolted to adjoining steel line flanges, avoiding any possibility of galvanic attack by insulating with Micarta tubes and gaskets at the flanged connections.

The light weight of aluminum pipe permitted use of the light single cable. This is said to cut labor cost for installation, allow a much smaller suspension to be used and eliminate painting or other types of maintenance.

Underground Lines: A number of test installations have been made in the underground use of aluminum pipe. Early in 1950, the Alabama-Tennessee Natural Gas Co. installed a 1.8-mile length of a new underground gas line to serve Reynolds Metals Listerhill, Ala., plant, using 8 1/2-in. outside diam, 1/4-in. wall, 63S-T6 extruded aluminum pipe. This pipe was furnished in 40-ft lengths with ends beveled for welding.

The light weight of the aluminum pipe permitted welding the pipe above ground to form 200-ft lengths, using roll welding technique where one man rolled the pipe over as the welder completed the weld. This allowed the welding to be made in the downhand position, increasing speed and efficiency of the operation. Then the 200-ft lengths were joined into the line by bell-hole welding.

The roll welding saved one-third to one-half in overall welding time, so that cost of line-up, bending, tacking and welding was only 9.6¢ per foot for the aluminum pipe.

Economies were also obtained in cleaning, priming, painting and wrapping.

No corrosion: When this aluminum line was installed, a 40-ft by-pass was installed around a 40-ft length of *bare* pipe as a means of permitting the bare section to be dug up and checked for corrosion at intervals.

First examination was made about a year and a half later (17 months to be exact) when this section was uncovered and brought out. Careful inspection of the pipe, both inside and out revealed no discoloration or corrosion of any sort.

Quite recently a second examination was made of the Alabama-Tennessee line. At this time, engineers dug up one of the aluminum flanges at the joint connecting the aluminum pipe to the steel line. This flange had not been wrapped and after 25 months of service no signs of corrosion could be found, Reynolds reports.

Submerged Arc Welding of Gondola Floors

AUTOMATIC submerged arc welding was employed in a new and time-saving application in the recent remodeling of 200 gondola cars by the Chicago, Burlington and Quincy Railroad at the Havelock, Neb. shops. The cars were to be equipped with new Nailable Steel Flooring which is held down by a 3/8- x 1 1/4-in. bar running the length of the car on each side. By means of the submerged-arc method the bars were fillet welded to the toe of the side-sill angle and the flooring was next welded to the opposite side of the bar by a second fillet weld also running the length of the car.

Two Unionmelt Type UE Heads mounted on Oxweld CM-37 machine carriages were used in each car, one for each side. Each machine rode on two 10-ft long fabricated aluminum tracks which were leapfrogged so that welding was continuous.

Welding speed for the 1/4-in. fillet weld between the bar and floor was 22 ipm at 400 amp., 26–28 v. For the weld between the side sill and bar welding speed was 32 ipm. Direct current was used on both operations. Welds were made using Oxweld 3/16-in. No. 29 rod and Unionmelt Grade 90 welding composition. All welded parts are low-carbon steel.

Fig. 1 Typical of the 84 Heliarc welding stations is this one where Nile Barber is welding a stainless-steel strut for a G-E jet engine. Automatic control of argon gas and water is assured by the new timer, with cover removed, on wall panel

Timer Cuts Heliarc Welding Costs

AN INGENIOUS new welding accessory, designed and built by the Ryan Development Laboratories, will save $3200 a month by taking the guesswork out of Heliarc welding. The device is a unique argon-gas and water-control unit which is completely automatic and foolproof in operation. It is being installed in 84 Heliarc welding stations where it will cut the $16,000-a-month argon gas bill by 20%.

To perform manual Heliarc welding, the operator is required to turn on the flow of argon gas and water before striking the arc. The argon gas provides a blanket of inert atmosphere which protects both the tungsten electrode and the weld area from oxidation at the high welding temperatures. The water is circulated through the torch to cool it and the electrical cables.

When the arc is broken, the operator must wait from 3 to 5 sec, to allow the electrode to cool sufficiently, before turning off the argon gas. Substantial amounts of gas are wasted in these starting and stopping procedures because the welder must depend upon his memory and judgment to control the time cycle. Necessarily, he must allow an excessive flow in order to be sure to exceed the minimum intervals.

Usually the argon-gas control is incorporated in the hook upon which the welding torch is hung. Consequently, if the operator stops welding but does not hang up the torch, the argon gas flows continuously. Frequently, it is necessary to stop welding to shift the part, pass over holding jigs or clean the torch. On these occasions the welder often does not hang up his torch and gas is wasted.

The gas-saving control is the product of the combined thinking of six development laboratory men: William Cockrell, Director; Don Heyser, Ford Lehman, Robert Fullerton and Fred Dever, welding engineers, and Wilson Hubbell, metallurgist. It consists of a few simple relays and condensers all of which are standard electrical parts with the exception of one special relay constructed by the laboratory. It contains no tubes or

Ryan Aeronautical Co., San Diego, Calif.

motors and requires no adjustments either for varied work setups or because of wear.

The timing cycle is started by means of a microswitch located in the foot pedal voltage regulator used for heliarc welding. As the operator depresses the pedal to obtain increased voltage for striking the arc, the microswitch is closed. This energizes two interdependent circuits, one of which immediately actuates two solenoid-operated valves to start the flow of gas and water. At the same time a condenser in the circuit is charged and begins to dissipate its current. It takes 8 sec for this condenser to discharge. If the arc is not struck within this 8-sec interval, the discharge of the condenser opens another relay which turns off the gas and water valves. If the arc is struck within 8 sec, the gas and water valves are kept open until the arc is broken. At that moment the automatic timing cycle is established.

The 8-sec interval is an inherent property of the condensers selected and is inevitably sequenced when the arc is broken regardless of what the operator does or does not do. Although 5 sec is sufficient time to cool the electrode to safe temperature, it was found that an 8-sec timing was better coordinated with the welder's work habits. In 8 sec he could break the arc, shift the work and resume welding without having to re-establish the timing cycle with his foot pedal.

Unlike some commercial controls, the unit is not sensitive to voltage. Consequently it is not rendered inoperative if the welder raises the foot pedal after striking the arc or when the voltage is deliberately reduced near the end of the weld seam. Also, it does not have to be adjusted in order to respond to the different voltages required for varied types of work.

It is completely positive and automatic under all welding conditions and requires no attention from the welder. He cannot strike the arc unless the gas and water valves in the control are open, thus eliminating the hazard of burning the valuable tungsten electrode. He is relieved of all concern about supervising the gas flow and can devote his skill to the welding itself to increase his production and reduce occurrence of defects.

The company has developed a hang-up switch which disengages the timing control from the welding equipment for use on 20 machines where both Heliarc and metallic arc welding are performed from the same generators. The operator can switch from Heliarc to metallic arc welding by simply hanging up one torch and picking up the other. Ryan has applied for patents covering the design of the gas-saving time control.

Heliarc Welding Helps Fabricate Nickel Pipe

HOT caustic soda solutions used by one chemical manufacturer will flow through a new, Heliarc welded wrought nickel piping system fabricated by the Gulf Coast Fabricating Co., Houston, Tex. Approximately 10,000 ft long, the piping system will carry caustic soda solutions at temperatures around 600° F, and higher.

Nickel is used for the system since it has excellent corrosion-resistance properties. Even at these high temperatures, corrosion rate of nickel by caustic soda is less than 0.020 in. per year.

More than 2700 ft of Heliarc welding is done on the piping system. Although pipe and fittings vary in diameter from $1^1/_4$ to 4 in., with wall thickness ranging from $^1/_8$ to $^3/_8$ in., all the welds are easily made. Welds are sound and pass inspection without any trouble.

Edge preparation for the joints varies. Some joints are hand-ground to a 45-deg included angle, others to a sharper angle with a $^1/_{32}$-in. root face. Two passes are used on all joints. The first pass is made without filler rod to obtain a uniform underbead. Then, a second pass is made, using nickel welding rod.

Welding current is direct-current straight polarity, about 100 amp. An argon gas flow of approximately 10 lpm (20 cfh) is used.

Nickel pipe used in the chemical industry is fabricated with Heliarc welding

Welded Desks Cut School Expansion Costs

EXPANDING school systems have increased the demand for attractive, durable, yet inexpensive desks and chairs. To meet this demand, the Arlington Seating Co. of Arlington Heights, Ill., has adopted Unionmelt and Heliarc welding to lower costs and speed production of school furniture.

One of the most popular desk-chair units produced by this company features a bowl-shaped swivel assembly upon which the seat is mounted to permit a limited arc of rotation. This assembly consists of two pieces, both of 14-gage mild steel. A round-plate, $6^3/_4$ in. in diameter, is Unionmelt welded to the top edge of the bowl-shaped second piece. A manual arc weld joins the seat post to the bowl-shaped piece.

An automatic positioning and holding setup, built by the company, has helped increase production by more than 500%. A turning jig locks the bowl-shaped piece in place while an air-operated hold-down clamp presses the top plate into position. Welding is done while the jig is turned by motor. Unused submerged melt welding composition is picked up by a vacuum unit mounted above the work. Welding time for the 21.1 in. circumference is 6 sec using 385 amp, d.c.r.p. Rod used is Oxweld No. 36, $^3/_{32}$ in. in diameter.

This welding was formerly done by open arc. Submerged melt welding has increased ouput while at the same time costs have been reduced. This is due to the high welding speeds of Unionmelt equipment and the absence of weld spatter or flux to be cleaned off.

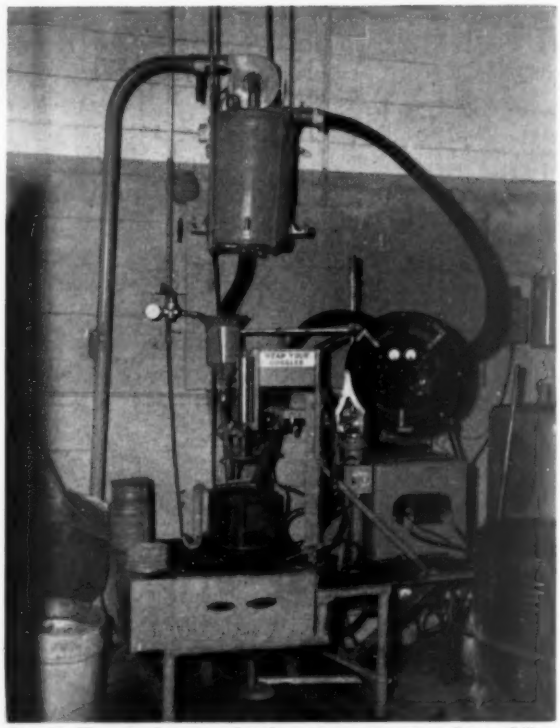


Fig. 2 Here is the completely automatic setup for welding swivel assemblies. The part rotates on the turning jig just below the welding head. Vacuum apparatus for recovering unused welding composition can be seen at the top

Fig. 1 These parts, when welded together, form the swivel assembly for the chair of a desk-chair unit

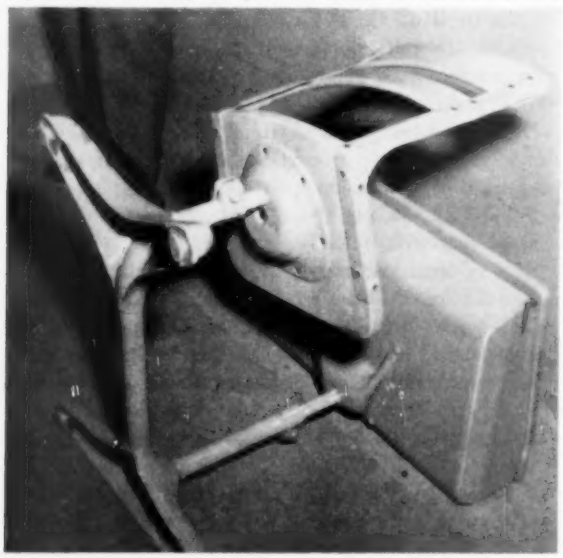


Fig. 3 Here the swivel cone assembly can be seen supporting the seat. No finishing work is needed on the smooth Unionmelt welds

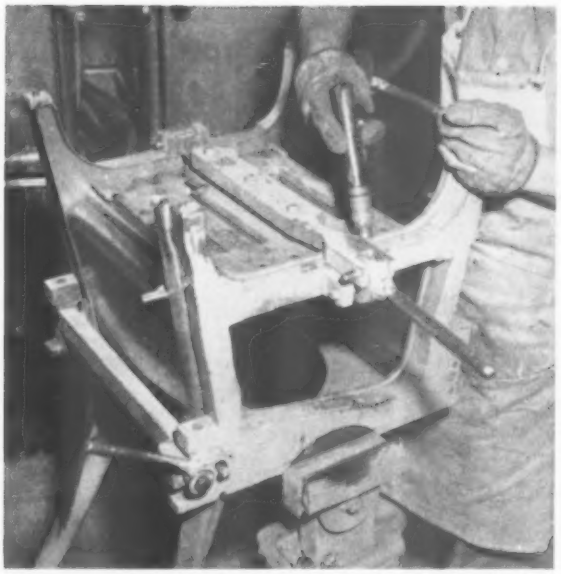


Fig. 4 This jig holds the two side pieces to the single piece book pan of a desk-arm chair while spot welds are being made with a Heliarc spot-welding torch

Another item that is popular in today's schools is a movable classroom chair which has an enlarged arm for a writing surface. Streamlined and comfortable, its design is possible only because of the Heliarc spot-welding process and an ingenious holding and positioning fixture.

Fig. 5 The size and maneuverability of the Heliarc torch makes spot welding possible in hard-to-reach places. At left is a spot-welded assembly; at right is a finished chair.

This fixture clamps both 16-gage chair sides to the 20-gage single piece book pen, forming the entire lower half of the chair, and permits the operator to revolve the unit during welding. Spot welds, requiring 2 sec each, are made in 25 places. One operator is able to triple previous production of chairs. Argon to shield the weld area from the air is consumed at a rate of 10 lpm. Welding current is 300 amp alternating current.

Cut Away Frozen Nuts and Rivets

by D. K. Feinthal

NUTS that remain in place for long periods often present a problem when they must be removed. Rusted threads and accumulated dirt can make what should be an easy job one that can take a lot of time and place an undue strain on the temper.

But there is an easy way to remove frozen nuts without using a wrench. In a matter of seconds your oxy-acetylene cutting blowpipe or cutting attachment can cut away the nut from the bolt without doing any damage to the bolt threads.

The first step of this easy way is to preheat the section of the nut to be cut away. Aim the preheat flames vertically at this area. When the metal becomes red under the flame, move the blowpipe into a horizontal position, as shown in the accompanying photograph, depress the cutting oxygen lever, and cut away the side of the nut.

Be careful not to cut too rapidly or you may damage the threads of the bolt. Just cut long enough to expose the bolt threads. Then, with a wrench, try to back the nut from the bolt. If it is still frozen, use your cutting blowpipe to cut away a larger section until the nut comes off easily.

Rivets can also be removed easily after cutting off the head. Use the size nozzle recommended for cutting steel 1 in. thick. Hold the nozzle parallel with the plate and cut a slot in the head similar to the slot in a round-head screw. As this cut nears the plate, swing the nozzle in a small arc, slicing off the head. The shank can now be driven out.

An oxy-acetylene cutting attachment substitutes for a wrench and removes this frozen nut faster and easier. And the blowpipe cannot slip and cause skinned knuckles

D. K. Feinthal, Linde Air Products Co.

Hard Facing

Oxy-acetylene or arc hard-facing processes? Job and metal determine which to use

by H. O. Jones

THERE are a number of methods of applying hard facing but outside of production lines, the most widely used are by the oxy-acetylene flame and the electric arc. In this article we will consider only these two applications and it is to be assumed that the most efficient operating procedures will be followed. When such procedures are practiced, the full value of the efficient use of each method is obtained.

THE OXY-ACETYLENE METHOD

In the early days of welding when the value of hard facing with various alloys was first recognized, the oxy-acetylene welding process was used in most cases. This method ordinarily produces the best quality deposits with the least amount of porosity, cracks and dilution with the base metal.

Oxy-acetylene application is preferred when a thin overlay of metal is required. It is especially recommended for precision motor parts because of the close control over the molten metal. It is very good for valve jobs on which a cobalt base material is used. The deposit can be put down very smoothly.

The reclaiming of Diesel engine valves, involving the application of a hard-facing alloy to the worn seat, is an excellent example of the proper use of the oxy-acetylene hard-facing method.

The first step in reclaiming consists of cleaning the valves thoroughly. Then the hard-facing alloy is applied to the worn seat. A carburizing flame is used and is kept pointed away from the stem to avoid distortion. Then the valve is centered in a lathe, the outside of the valve is trued up, and the seat machined to size. Finally the seat is finished in a valve grinding machine.

These reclaimed valves, measuring from 4 to 5¼ in. in diameter, have a service life of three to four times that of new valves.

In general, particles of scale and foreign matter are eliminated more easily by the oxy-acetylene method, and edges and corners can be formed readily. This is particularly important when grinding the part to a finished dimension is necessary.

Application of hard-facing material by the oxy-acetylene flame to cutter bits, sprocket teeth, clutch jaws, chains, worm gears and cutter-bar ends is very effective. On the other hand, teeth, blades and other parts of road machinery and earth-moving equipment, which wears rapidly when made of unhardened steel, are effectively hard faced by the electric arc method.

H. O. Jones, Air Reduction Sales Co, New York, N. Y.

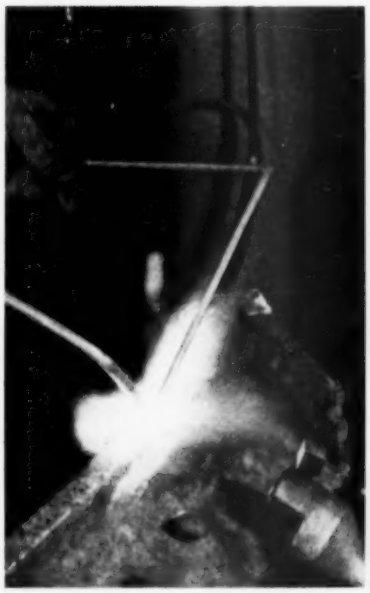


Fig. 1 Gas Method

Photos courtesy Air Reduction Sales Co.

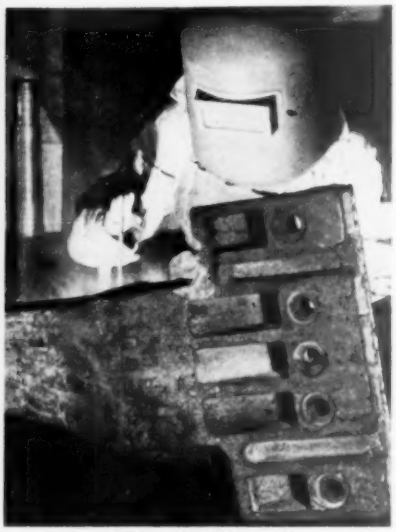


Fig. 2 Arc Method

ELECTRIC ARC METHOD

While both the oxy-acetylene and electric arc methods of application are effectively used on a wide range of metals such as low- and medium-carbon steels, high-carbon steel, low-alloy steel, stainless steel, cast iron and malleable cast iron, the particular requirements of each job will clearly indicate the use of one method over the other. On manganese steel, incidentally, the electric arc method only is recommended. Typical parts include crusher jaws and dredge cutter blades.

Electric arc application is advantageous for large areas over irregularly worn surfaces or where a fine finish or precision dimensioning is not necessary. Speed of deposition is greatly increased over the oxy-acetylene method. It should be remembered, however, that the single layer deposit made by the arc tends to result in a deposit somewhat diluted with the base metal, softening the deposit and reducing its resistance to abrasive wear. The dilution effect can be minimized by depositing a thin first layer followed by a second layer thick enough to restore the worn part to its original dimensions. In general, the arc method is particularly suitable for hard-facing all heavy parts where exceptionally thin, smooth deposits are not required.

In hard-facing cast iron, less difficulty is encountered with the electric arc than with the torch because of the extremely high temperature of the arc. This extreme heat releases the impurities and usually melts out the surface porosity of the cast iron.

For hard facing excessively worn parts, although many successful applications are made with oxy-acetylene, the arc process should be used whenever possible to build up the worn area to within ¼ in. of the finished dimension. As a general rule, actual hard-facing deposits should be restricted to ¼ in. or less.

So, whether by the oxy-acetylene or electric arc process, it can be said in summary that the possibilities for hard facing are countless. If industrial and agricultural equipment is subjected to abrasion, impact, heat or corrosion, hard facing will multiply its life many times.

the AMERICAN WELDING SOCIETY

activities • related events

1953 Adams Lecturer

Rex Beaumont Shepheard C.B.E., B.Sc., M.I.N.A.

The Board of Directors of the AWS upon nomination of the Committee on Awards has selected Rex Beaumont Shepheard to give the 1953 Adams Lecture. Mr. Shepheard has selected the title of "Aspects of Welding Research in British Merchant Shipbuilding."

Mr. Shepheard is Director of the Shipbuilding Conference, London. A graduate of Glasgow University in Naval Architecture, he joined Lloyd's Register of Shipping as a Ship Surveyor in 1928, serving before the War in London, Glasgow and Hamburg.

In 1941 he was transferred to Richmond, Calif., during the building of the 30 Ocean-type welded cargo ships. He was seconded in the following year to the Admiralty as Superintendent of Welding Development on the staff of the late Sir Amos Ayre, then Director of Merchant Shipbuilding. He was appointed Chief Ship Surveyor of Lloyd's Register in 1944, relinquishing this position in September 1952, to take up his present duties.

Mr. Shepheard is a Member of Council of the Institution of Naval Architects, Member of Council of The British Shipbuilding Research Assn. and of the British Welding Research Assn., and Member and Chairman of the Sub-Committee of the Admiralty Ship Welding Committee.

He was appointed a Commander of the Order of the British Empire in 1949.

Recommended Practices for Spot-Welding Aluminum and Aluminum Alloys

(33 pages, illus., published by AWS)

After more than four years of effort involving a compilation of data and making tests, the AMERICAN WELDING SOCIETY has just issued the *Recommended Practices for Spot Welding Aluminum and Aluminum Alloys*. This standard was called the most complete and most valuable publication of its kind by a large group of welding engineers who were asked to review and discuss a preliminary draft at a symposium in 1952.

Because the welding of aluminum requires certain special considerations it was necessary to issue these Recommended Practices in a separate bulletin, rather than include them with the Recommended Practices for steels and other metals issued in 1950.

This is a manual of practical design and manufacturing data. Included is a table showing the combinations of aluminum alloys which can and cannot be spot welded. Mechanical cleaning and specific chemical cleaning methods are given for removal of surface oxide and foreign matter prior to welding.

Complete welding schedules are given for frequency converter machines; rectifier machines; electromagnetic and electrostatic stored-energy machines; and standard a-c machines. The electrical and pressure characteristics of these machines are illustrated and suggestions provided for altering the welding schedules for specific applications.

A complete chapter is included on weld defects, illustrated by photographs, and including a discussion of the causes of different defects.

The Appendix contains a bibliography of 58 articles on aluminum spot welding for further information on specific aspects of the subject.

Copies of the *Recommended Practices for Spot Welding Aluminum and Aluminum Alloys* are available at $1.00 each, from the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

Weldability of Steel

Weldability of Steels, published by Welding Research Council, 29 W. 39th St., New York 18, N. Y., was written by Robert D. Stout, Ph.D., Professor of Metallurgy, Lehigh University, Bethlehem, Pa., and W. D'Orville Doty, Ph.D., Welding Metallurgist, United States Steel Corp., Pittsburgh, Pa.

This book, priced at $6.50, consists of 381 pages handsomely bound in Fabrikoid leather hard covers and copiously illustrated.

The weldability of carbon and low-alloy steels is at once one of the most interesting and one of the most challenging of engineering problems. During the past 15 years it has engaged the attention of hundreds of investigators, from whose laboratories has flowed a mass of information so voluminous that there has been little opportunity for an over-all analysis and interpretation.

The Weldability Committee of the Welding Research Council realized that if these experimental results were to be of practical use to welding and design engineers, it would be helpful to prepare a critical analysis and digest in the form of a monograph. The authors were commissioned to prepare such a volume which they have done well.

Since it is impossible to discuss weldability without reference to welding processes and metallurgy, the early chapters of the monograph cover briefly the fundamentals of these subjects in relation to weldability. Next comes consideration of the basic factors which influence the weldability of carbon and low-alloy steels, after which are presented suggested methods for welding commonly used steels. The remaining chapters contain a review and critical evaluation of weldability tests and general conclusions on our knowledge of weldability.

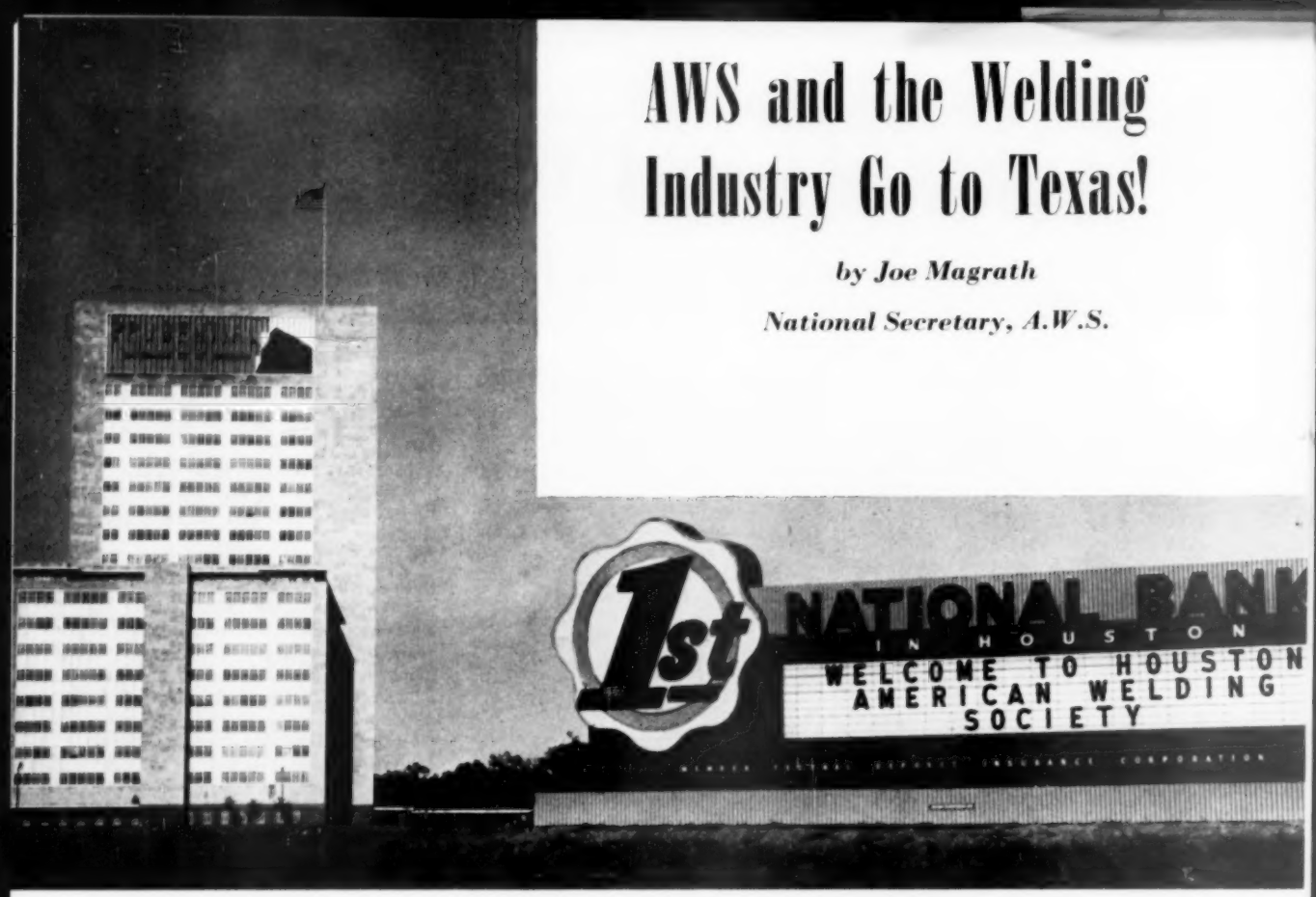
Probably the most widely useful part of the book is an Appendix consisting of 50 pages of tables wherein all of the standard specification steels, such as ASTM, SAE, ABS and others, are classified into three catagories, those which are readily weldable, those in which some precautions are needed and, finally, those which require special precautions and considerations. Exact welding procedures are indicated for each thickness of steel. These procedures tend to be a bit conservative but are based on the best knowledge available to date.

A limited edition of this book has been published and the distribution is being handled by the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

AWS and the Welding Industry Go to Texas!

by Joe Magrath

National Secretary, A.W.S.



Coincidence, but fitting! Behind the welcoming electric sign, rose the beautiful Texas home of the Prudential Insurance Co., an all-welded structure, symbolic of strength, permanence and confidence in America's and welding's future

Houston will be remembered a long time.

It will be remembered—

—because in Houston was fulfilled the faith of those in our Society and Industry who at no time in their own mind or voice, doubted or cast a doubt that an all AWS activity in the Southwest would meet with success.

—because in Houston it was proved that a comprehensive and extensive technical program was wanted and supported by a day-for-day-meeting audience, exceeding in numbers per meeting, the attendance at national fall meetings in other cities of concentrated industrial and engineering population. Seven hundred and ninety-eight persons paid a registration fee to attend the Society's technical sessions. Our optimistic estimate, prior to the meeting, was 800.

—because in Houston it was proved that the Welding Industry would and could join in united exposition of their products and processes, and as a group of vertical objective, produce a display of action, quality and interest. Seventy-seven organizations displayed their wares in exhibits varying in size from 1 to 13 booths for each. Actually in the 77-unit displays, the wares of more than 250 manufacturers were exhibited. At Houston were assembled the largest number of Welding Industry Exhibitors even before brought together in one cooperative effort —harmonious, educational, productive.

—because in Houston it was proved that an *all-welding* show attracts an attendance of *all-welding* interest. Every attendee who passed through the gate (over 5000 clocked) came because he was *interested* in welding. He was a welding prospect by nature of his having come to the show. He knew welding. There was no time lost in searching for the occasional welding prospect from within a group of 10 to 20 suspects. *Each* attendee *was* a prospect. The exhibitors' booth personnel quickly learned that here at last was an attendance that *knew* welding, *knew* welding equipment, appreciated the value of those new welding ideas offered, and understood that which he was being told. Thus, the time of booth personnel was utilized to the maximum productivity. It was observed by many that literature was not "grabbed" in volume and, later, after booth by booth accumulations, to be discarded in a corner or outside on the pavement. Instead, only that literature pertinent to the interest was taken or requested. The attendance was one of quality and intelligent interest; one directly concerned with the use of welding procedure and product, its specifications or its purchase.

From the moment of its opening at 12:00 noon on Tuesday, June 16th, to the closing hour at 6:00 P.M. Friday, June 19th, there was constant activity on the Exposition Floor. The exhibiting manufacturers and representatives of the Welding Industry are sincerely congratulated upon their exhibits, the styling thereof, the extent of their displays, the adequacy of booth manpower and the care and attention they gave to each visitor. Throughout the four days of exposition, the four- or five-installation and three- or four-dismantling days, there prevailed a wonderful feeling of cooperation, good will and helpfulness. Courtesy seemed to be the objective: between exhibitors, exposition floor management and the local labor. As a result, when the doors were opened soon after the official "cutting of the chain," every booth was in order, ready to offer the services of our industry to our visitors. Our Society desires to express its sincere appreciation to the American Welding Industry who made it possible for AWS to hold its Welding and Allied Industry Exposition in Houston in 1953.

President F. L. Plummer supervises the oxy-acetylene "cutting of the chain," opening the AWS Welding and Allied Industry Exposition at 12:00 noon, Tuesday, June 16, 1953, Houston, Tex.

Registration for AWS Member and Guest attendees to the Technical Sessions started on Monday in the Shamrock lobby—798 participated in these sessions

Technical sessions were held in three famous Shamrock rooms: Emerald, Shamrock and Grecian. The "Human-Element-in-Welding" session is starting in the Grecian Room

Col. Thurston T. Paul, Watertown Arsenal, Chairman of the Titanium Session, C. E. Hartbower, Co-Chairman, and J. C. Barrett of the U. S. Bureau of Mines, who gave the opening address

President F. L. Plummer, Mrs. Plummer and their two daughters enjoy the pleasant atmosphere at breakfast on the Terrace, overlooking the Shamrock Pool

All of the 14 technical sessions, comprising 35 papers prepared by 58 authors of national and international status, drew large attentive audiences from the 798 technical meeting registrants. The meeting room facilities were exceptional for the comfort, clear vision and hearing of the attendees. Two co-chairmen, selected for their knowledge of and interest in the papers, presided over each session, ably assisted by two Houston AWS Members who gave volunteer service as Meeting Room Supervisors. On Tuesday and Wednesday, large groups toured the plants of the A. O. Smith Corp. (Texas) and the Hughes Tool Co., which organizations cooperatively provided capable guides for conducting groups through those departments of activities in which they knew our members and guests were interested.

The Shamrock Hotel itself was intriguing to the ladies, the beautiful swimming pool and its semitropical garden with overlooking terrace serving as the center of their interest and competing with the hotel fashion and gift shops. The ladies' interests were divided between an honorary tea and fashion show at Sakowitz's, a tour of Houston, a tour of the Shamrock kitchens and an afternoon and evening outing (by bus and boat), to the San Jacinto Battleground, Monument, Museum, Battleship *Texas* and San Jacinto Inn where, after refreshments, they joined with the men at a Captain's dinner which weighted the tables but was quickly transferred to personal avoirdupois to be carried homeward to their hotel after a full day of activity.

The National Society extends its sincere, warm appreciation to the AWS Houston Section Officers, Membership and their ladies. The Houston folks, hosts to their national guests, at the dinner and at various other activities, went all out in effort and proved that Texas and Houston hospitality is everything that it has been claimed. We salute Houston and thank everyone for a grand convention.

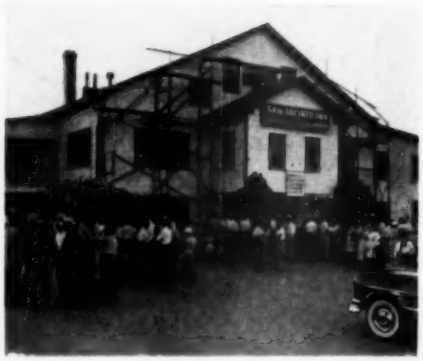
Cleveland, October 1953

Since late 1952, our National and Cleveland Committees have been working on the program for the Fall Technical and Annual Meeting to be held in the Hotel Cleveland, at Cleveland, Ohio, Oct. 18–23, 1953. The American Welding Society will be one of the four societies sponsoring the National Metals Congress and Exposition.

The program will include the President's Reception, Plant Visits, Annual Business and Board Meetings, Annual Dinner, Adams Lecture, Awarding of Prizes and other activities. A tentative program of technical papers was included in the July issue of The Welding Journal.

(Left) Mrs. Boardman and Is Morrison, Board of Directors, listen to Harry Boardman, Chairman of Program Committee, tell one of his mathematical formula twisters. The eggs are getting cold!

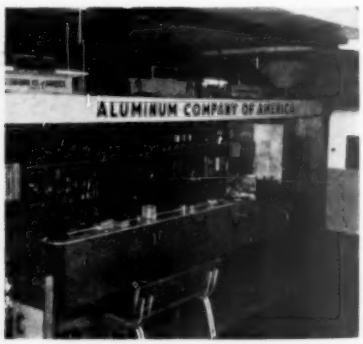
(Right) Over 350 members and guests gathered together for refreshments at San Jacinto Inn after a bus and boat tour. (Below) Consuming about a ton of seafood, chicken and biscuits at the Captain's dinner



(Above) Tough for the cameraman! This fashion bloc at the Battleship Texas consists of Joe Magrath, Fred Plummer, Al Wisler, Hiro Mikami, Ed Dato, Mac MacGuffie, Ben Allen and Harry Boardman

(Right) Everybody was a Texan! Even President Fred Plummer who got in by right of his Texas passport

(Below) The Welding Manufacturing Industry did an outstanding job with 77 attractive, educational and demonstration exhibits. Three of these are shown, prior to the opening, illustrating the quality of the Houston displays



Low Temperature
EUTECTIC
WELDING ALLOYS

JB. -
this will interest
you!

NEW YORK

EUTECTIC TO HOLD FIRST COMPARISION SEMINAR ON ADHESIVES

Synthetic Resins VS. Brazing and Soldering

Flushing, N.Y.—The first comparison seminar ever held on organic bonding is scheduled for the early Fall by the Eutectic Welding Alloys Corporation at its training institute in Flushing. It will continue for four days; is open to all who wish to investigate the adhesive bonding of materials, and should prove invaluable to design engineers, production men, and all who have problems in bonding.

"Industry has long felt the need," stated Rene D. Wasserman, president of the corporation, "for some reliable data upon adhesives in which a comparison is made with conventional joining materials. Such information from a company manufacturing adhesives might be considered prejudiced in favor of its products and the same applies to a firm manufacturing welding materials.

"Eutectic's position as a pioneer in the research and manufacture of solders, brazing and welding alloys enables it to speak authoritatively on this subject. It can speak similarly upon adhesive bonding because of its ChemoTec Division which was organized to develop organic bonding agents. It is thus in the unique position of being able to tell the unbiased truth of the advantages and limitations of adhesives in general and the epoxy adhesives in particular."

Speakers of repute, all experts in their chosen fields, have been approached. All welcomed the idea as one which will do much to clarify a very obscure situation. A metallurgical engineer will explain what can be done with metals and, within the limits of present day knowledge, what cannot be done. A man who has grown up with the plastic industry will discuss synthetic resins. Well known design engineers will state their experiences, their successes and failures. They will explain how a simple change in design can increase productive capacity and take advantage of modern bonding materials. Production men will report upon curing cycles and how production schedules are improved or complicated. They will compare the high skill necessary to produce a satisfactory welded joint, with the small amount of skill required when adhesives are used.

All schools of thought will be represented and the theory expounded will be put to a practical test so that definite conclusions may be drawn.

Certain factors must be explained in detail and in relation to the metallurgical or organic nature of the bonding agent. The tensile strength of a specially formulated epoxy resin base adhesive, may be more than adequate for the joint involved. The peel strength, however, may be negligible. This weakness, common to many adhesives, can be counteracted by a change in design. This feature, the importance of design, will be stressed throughout the seminar. Butt joints are practical only if the filler has good adhesion and strength. A solder conceivably could have an adhesive strength at the interfaces of 50,000 psi. through alloying with the parent metal, but the strength of the joint would be that of the solder. Thus if the solder had a tensile strength of 6,000 psi. this would be the breaking point of the joint despite the high strength at the interfaces.

Soldered and brazed joints will be demonstrated, after which similar parts will be adhesively joined. Comparisons will be made, the advantages and disadvantages pointed out, and then demonstrations will be given to show how a simple change in joint design can give an adhesive joint the strength of a brazed one.

Synthetic adhesives have certain characteristics which make them ideal for certain operations. Their wettability is unique. They wet, not only all metals, but most non-metallic, non-porous, or porous surfaces. This will be shown in contrast to conventional soldering where elaborate treatment is necessary upon unprepared metal.

The advent of paste solder, which combines solder and flux in the form of a paste, has eliminated many of the disadvantages of conventional solder. A comparison test will be made with this material to show how its thin flowing, self fluxing action facilitates the bonding of long lap joints. The flowing qualities of adhesives will then be tested upon similar joints.

Case histories will be examined to show actual applications; their study will determine their efficiency compared to methods previously used. Joining emblems to semi precious stones was done originally by means of rivets. A change over to organic bonding reduced the number of operations from 12 to 6. The cost was reduced proportionately and rejects were practically eliminated.

Case histories such as this will be used to show how others have adapted the latest organic bonding techniques to reduce the number of operations and produce a more satisfactory product.

It is hoped this seminar will be a real contribution to industry and will make known the conditions under which an adhesive bond will be satisfactory—and when it will be unsatisfactory. The corporation feels it is in a unique position to demonstrate both bonding methods and to leave industry to select that most suitable for its requirements.

The seminar will be presented as a service to industry. There will be no charge, but those attending will be expected to pay their own transportation and accommodation charges. Requests for further information should be made to Eutectic Welding Alloy Corporation, 40-40 172nd Street, Flushing, New York.

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and get more
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EUTECTIC WELDING ALLOYS CORPORATION • 172nd Street & Northern Blvd. • Flushing 53, N. Y., N. Y.

NEWS OF THE INDUSTRY

Special Welding Course

The Lincoln Electric Co., 22801 St. Clair Ave., Cleveland 17, Ohio, is announcing a one-week welding course for farm mechanics, instructors, industrial arts teachers, teacher trainers and district supervisors from August 24th to the 28th.

The special summer course for those interested in teaching welding will again be held this summer. As in the past, there will be training in welding, soldering, brazing and hard surfacing, with particular emphasis given to how to teach those subjects.

No previous experience is necessary. This course is for teachers, not welding operators and, consequently, is just as good for the beginner as for those with experience.

The course will be held at the company's new plant in Cleveland, Ohio. It will be conducted by personnel who are familiar with the problems of a shop instructor and have experience in teaching in that field. The Lincoln Welding School Staff will also be on hand to help give close personal instruction.

Welding Exhibition

Olympia, London
Sept. 3–17, 1953

The Nineteenth Engineering, Marine and Welding Exhibition and the Chemical Plant Exhibition, occupying more than a quarter million square feet will both be held at Olympia, London, from September 3rd to September 17th.

For nearly fifty years this Exhibition, which has been held in alternate years except when interrupted by the two world wars, has presented to industry throughout the world a massive and unrivaled display of engineering quality and achievement.

Safety Films

The National Safety Council has just published the 1953–54 edition of the National Directory of Safety Films.

The directory provides the plant safety man with a comprehensive listing of 963 motion pictures and slide films for use in training personnel in occupational accident prevention. Films on home and traffic safety are included for the off-the-job safety program.

Copies of the directory are available for 75 cents each from the National Safety Council, 425 N. Michigan Ave., Chicago 11, Ill.

Safety Meeting

The 41st National Safety Congress and Exposition will be held October 19th to October 23rd at Chicago, Ill. Sessions on industrial safety scheduled for Conrad Hilton, Congress, Morrison and Hamilton hotels; traffic safety sessions at the Congress Hotel; commercial vehicle and transit safety sessions at the La Salle Hotel; farm safety sessions at the Palmer House; school safety sessions at the Morrison Hotel and home safety sessions at the Conrad Hilton Hotel. For further information write R. L. Forney, General Secretary, National Safety Council, 425 N. Michigan Ave., Chicago 11, Ill.

Arc Welding Contest

The James F. Lincoln Arc Welding Foundation of Cleveland, Ohio, has announced a $13,500 Arc Welding Award Program for Selected Business and Service Establishments. Men or women engaged in any of the selected businesses may be able to earn an extra $1000 this year by describing the use or possible use of arc welding in the maintenance, operation or services performed by the business. Awards will be made to individuals in nonindustrial businesses and service establishments such as bakeries, dairies, hospitals, hotels, food manufacturers, buildings, municipalities, cemeteries, printing plants and newspapers. The 40 different types of eligible establishments cover nearly all nonindustrial types of organizations.

Written descriptions of how arc welding is or can be used in the maintenance or operation of the business or service will receive awards ranging from $1000 to $25. A total of 191 awards will be made to individuals in these businesses.

None of the selected businesses or establishments is in a metal fabrication field where welding is generally used. These have been eliminated to limit the program to people who have similar opportunity for using welding.

An illustrated booklet of Rules for the Program is available from The James F. Lincoln Arc Welding Foundation, Cleveland 17, Ohio.

Clad Steel Movie

A nontechnical film documents the success of a variety of key industries in obtaining new profits through the operating economies of clad-steel equipment. The 16-mm Kodachrome film produced by Robert Yarnall Richie and released by Lukens Steel Co. for the benefit of distributors, fabricators and ultimate users of clad steels has a running time of 30 min.

Eutectic to Hold First Comparison Seminar on Adhesives

The first comparison seminar ever held on organic bonding is scheduled for the early Fall by the Eutectic Welding Alloys Corp. at its training institute in Flushing. It will continue for four days; is open to all who wish to investigate the adhesive bonding of materials, and should prove invaluable to design engineers, production men and all who have problems in bonding.

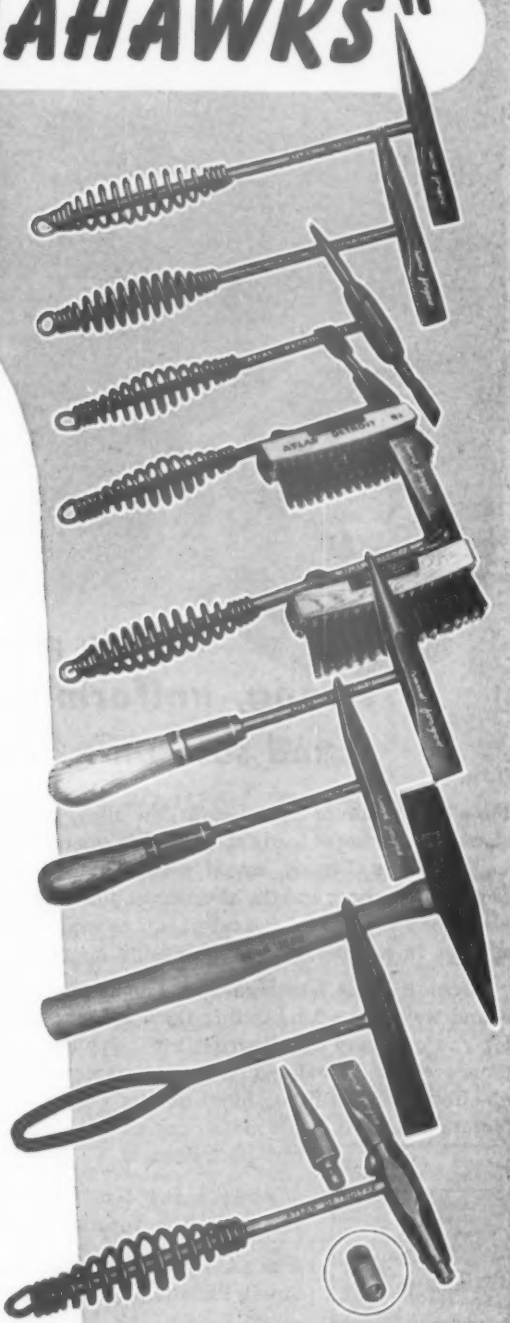
Speakers of repute, all experts in their chosen fields, have been approached. All welcomed the idea as one which will do much to clarify a very obscure situation. A metallurgical engineer will explain what can be done with metals and, within the limits of present-day knowledge, what cannot be done. A man who has grown up with the plastic industry will discuss synthetic resins. Well-known design engineers will state their experiences, their successes and failures. They will explain how a simple change in design can increase productive capacity and take advantage of modern bonding materials. Production men will report upon curing cycles and how production schedules are improved or complicated. They will compare the high skill necessary to produce a satisfactory welded joint, with the small amount of skill required when adhesives are used.

The seminar will be kept to a practical level. The theory of bonding will be discussed but metallurgy will be held to a minimum. The needs of industry have been studied and the company feels the time devoted to theory should be sufficient only to indicate why these joining problems exist.

The seminar will be presented as a service to industry. There will be no charge, but those attending will be expected to pay their own transportation and accommodation charges. Requests for further information should be made to Eutectic Welding Alloys Corp., 40–40 172nd St., Flushing, N. Y.

"ATLAS TOMAHAWKS"

WH-20
WEIGHT 14 ozs.
LENGTH 11"



Featured above is one of 3 new WH Models, each with a different head style. Like all Atlas Tomahawks WH-20 is tough, has balance and endurance. For those who prefer wood handle tools, there's nothing better. Ask your Dealer for Form WCF32A describing all 28 models of Atlas Tomahawks.

PROVED PRACTICAL ATLAS WELDING ACCESSORIES

Atlas WELDING ACCESSORIES CO.

707 E. LEWISTON AVENUE, FERNDALE 20 (DETROIT) MICH.

How to produce
strong, uniform welds
and save time doing it

Mine cars made of light weight low alloy, high strength steels mean bigger loads at savings in operating costs for mine owners. Strong, sound welds—able to resist the impact of loading, and the abrasion of filling and dumping also mean savings for the fabricator as well as additional savings in maintenance for the mine operator.

Because Arcos Low Hydrogen Electrodes can produce sound welds on a job like this, they can do the same thing for you on every *application* involving low alloy, high tensile steels. Whatever your requirements, there's an electrode to meet them. Rigid quality controls in manufacture assure you weld metal consistently high in quality and performance.

ARCOS GRADE	A. W. S. SPEC.
Tensilend 70	E7016
Tensilend 100	E10016
Tensilend 120	E12015
Manganend 1M	E9015
Manganend 2M	E10015
Nickend 2	E8015
Chromend 1M	E8015
Chromend 2M	E9015

Write today for "The ABC's of Welding High Tensile Steels".

Arcos Corporation, 1500 South 50th Street, Philadelphia 43, Pennsylvania

WELD WITH
ARCOS
LOW HYDROGEN ELECTRODES

ASTM Officers for 1953–54

The following new officers have been elected by the ASTM to serve for the ensuing fiscal year:

President (term—one year): LESLIE C. BEARD, JR., Assistant Director of Socony-Vacuum Laboratories, Socony-Vacuum Oil Co., Inc., 26 Broadway, New York 4, N. Y.

Vice-President (term—two years): CLAIRE H. FELLOWS, Director, Engineering Laboratory, and Research Department, The Detroit Edison Co., 2000 Second Ave., Detroit 26, Mich.

Members, Board of Directors (term—three years): NEIL A. FOWLER, Director of Sales and Research, General Box Co., 1825 Miner St., Des Plaines, Ill. RICHARD T. KROPF, Vice-President, Industrial Thread Division, Belding Heminway Corticelli, 1407 Broadway, New York 18, N. Y. THEODORE E. OLT, Director, Research Laboratories, Armco Steel Corp., Middletown, Ohio. JOHN R. TOWNSEND, Director of Material and Standards Engineering, Sandia Corp., Sandia Base, Albuquerque, N. Mex. KENNETH B. WOODS, Associate Director, Joint Highway Research Project and Professor of Highway Engineering, Purdue University Engineering Experiment Station, Lafayette, Ind.

Appointments in G-E Welding Department

Three men have been named to new posts in the General Electric Co.'s Welding Department at Fitchburg, Mass., it was announced recently by Charles I. MacGuffie, manager of marketing for the department.

They are Charles L. Helms, manager of marketing administrative practices; Austin Hiller, manager of marketing analysis and planning research; and Austin Leach, manager of renewal parts.

Mr. Helms has been serving as manager of sales services for the department. He came with the Company in 1928 at Schenectady, N. Y., and spent several years with G-E at Bloomfield, N. J., New York City, and Houston, Tex. Prior to his transfer to Fitchburg, in 1949, he was manager of the Houston office for the Welding Department.

Mr. Hiller joined the General Electric X-Ray Department at Milwaukee in 1946. He transferred to the Welding Department in 1950 as a sales engineer and was stationed in Chicago. Mr. Hiller is a graduate of the Carnegie Institute of Technology and is a native of Pittsburgh, Pa.

Mr. Leach, a graduate of the University of Texas, started his career with G-E in 1941 as a test engineer at Schenectady. He

was stationed at the Dallas office of the Welding Department from 1946 to 1950, when he was transferred to Fitchburg as a sales engineer.

Air Reduction Announces Research and Engineering Changes

Four Research and Engineering Department changes have been announced by Air Reduction Co., Inc.

Dr. L. I. Gilbertson has been appointed Director, in charge of the company's Murray Hill (N. J.) Laboratories. He was formerly Administrative Manager at that location. Dr. G. B. Carpenter has been named Manager of the Development Staff with headquarters in New York. He was formerly Manager, Chemical Division, at the Murray Hill Laboratories. Drs. Gilbertson and Carpenter will report to Dr. Georve V. Slottman, Vice-President, who announced the new appointments.

Simultaneously, Dr. Slottman announced two other changes at the Murray Hill Laboratories. Dr. A. Muller was appointed Director of Metallurgical Research. He was formerly Manager, Metallurgical Division. Dr. B. C. Redmon, formerly with U. S. Industrial Chemicals Co., has been appointed Director of Chemical Research. Both Dr. Muller and Dr. Redmon will report to Dr. Gilbertson.

Reconditioning Operations

Straight line mass production techniques and economies are now being applied by The Lincoln Electric Co. of Cleveland, Ohio, to the reconditioning and rebuilding of arc welding equipment. The new rebuilding techniques are employed in a new operating division established by Lincoln as a result of studies undertaken by plant engineers following the company's move into its new $10,000,000 plant. The new division of the company called the Line-conditioning Division, with $500,000 in space and equipment, utilizes conveyor lines and line operations to realize efficiencies in rebuilding welders, work which is normally done on a one-at-a-time basis.

The new division, under the supervision of Robert Dalzell, will rebuild for users of Lincoln equipment their engine-driven motor generator and a-c welders. By rebuilding welders in production lots, assembly line methods of dismantling, reconditioning and reassembly can be used to achieve production economies that are impossible if only one or two machines are processed at one time.

Because the same specialized skills and tools that are used in manufacturing are also used in rebuilding, new machine guarantees are placed on all welders that

How to
tame corrosion *fast and effectively on welded joints*

Chemical tanks and equipment must have more than the proverbial nine lives to withstand incessant corrosive attack.

Proper plate material and good joint design are basic. The choice of the right electrode in some cases may be relatively easy—but always highly important. In other cases, where the corrosive action is intensified by heat and perhaps pressure, the proper balance of the chemical, physical and metallurgical properties in the weld metal will be critical.

For every *stainless* job, whether it be relatively simple or critical . . . there's an Arcos quality-controlled electrode that will pay handsome dividends in sound trouble-free *weld metal.* Send for a free copy "What Electrode Would You Use?"

Arcos Corporation, 1500 South 50th St.
Philadelphia 43, Pennsylvania

WELD WITH ARCOS
STAINLESS ELECTRODES

are Line-conditioned. A firm price covers the rebuilding of Lincoln welders in this new division.

New techniques for rebuilding electrical equipment, gasoline and Diesel engines have been developed and worked into conveyor line procedures. All parts of engines, motors and generators are completely disassembled, cleaned, stripped, checked for condition, rebuilt, reassembled and given standard factory final tests. Electrical parts that need rewinding are put through the company's regular production lines. Gasoline and Diesel engines are rebuilt by standard factory methods by men trained in manufacturers' plants. The reassembled welder is given final tests and painting that meet factory inspection standards. The Line-condition Division is tooled up to handle several hundred machines per month.

Eutectic Breaks Ground for New Plant

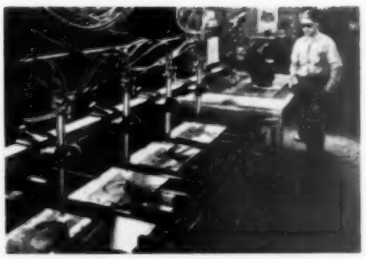
A "groundbreaking" ceremony was held recently by the Eutectic Welding Alloys Corp. for its new No. 3 Plant to be built on land adjoining Plant No. 1. Rene D. Wasserman, President of the corporation, announced the purchase of the most modern equipment available for high-speed production of the new types of electrodes recently developed by the company to fill orders for Government and civilian agencies.

A fully mechanized production line 273 ft long will be installed and a sixth press has been ordered which will be one of the largest ever used for this type of work. Included in the equipment on this huge production line will be special furnaces, mixing equipment and wire processing equipment. The raw material will enter at the north end of the new building, pass through the various processing stages and the finished electrodes will leave the production line at the south end where they will be carried due east into the shipping department.

Air Reduction on TV at Houston Welding Show

Air Reduction used closed-circuit television in their exhibit at the AMERICAN WELDING SOCIETY Show, Houston, Tex., so that a greater number of visitors would have a better view of the welding demonstrations. DuMont's new "Tel-Eye" portable, self-contained TV camera was placed in the welding booth and just a short distance away, perched 8 ft above the floor, were three large-screen receivers which permitted all to see close-ups of the welding arc in action. It was estimated that TV increased tenfold the number of persons able to witness a "live" welding demonstration.

An all-aluminum welding booth (10 x 16 ft) housed the TV camera, welding



Electronic Tracer (right) automatically follows ink drawing or paper cut-out template

equipment and operators—11 push-button operated windows were lowered after each demonstration so that the welding operation observed on TV could be inspected first-hand by interested persons.

Three demonstrations were televised successfully—Manual Aircomatic Welding, an experimental Aircomatic Pipe Welding Machine and Automatic Heliweld Hardfacing.

An experimental model of an aluminum pipe welding machine was demonstrated and Airco's new Automatic Heliweld Hardfacing Unit also was shown in operation.

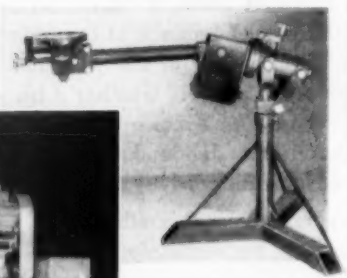
A multiple-torch oxy-acetylene shape-cutting machine—the Airco 6B Oxygraph—was in operation in the booth. The torches were automatically guided by an Electronic Tracer which operates on the "electric eye" principle, following a

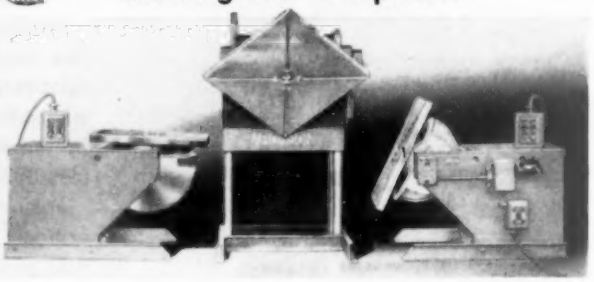
$ Aronson POSITIONING $ PAYS OFF! $

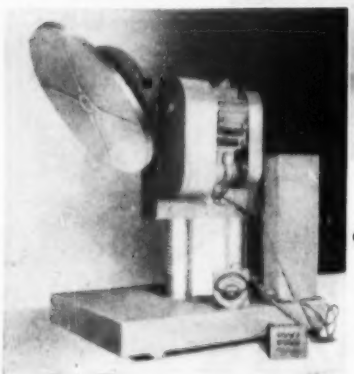
"Downhand" says: "Send for our latest price list showing new low prices!"

HEAVY DUTY GEAR DRIVEN POSITIONING
Model HD 25 shown
500 lbs. to 10,000 lbs. capacity

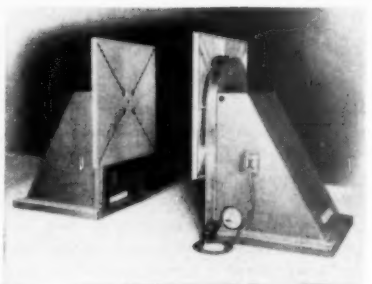
UNIVERSAL Balanced POSITIONING
Model C 1000 shown
25 lbs. to 2,000 lbs. capacity







HEAD and TAIL STOCK POSITIONING
Model HTS 32 shown
5,000 lbs. to
32,000 lbs. capacity

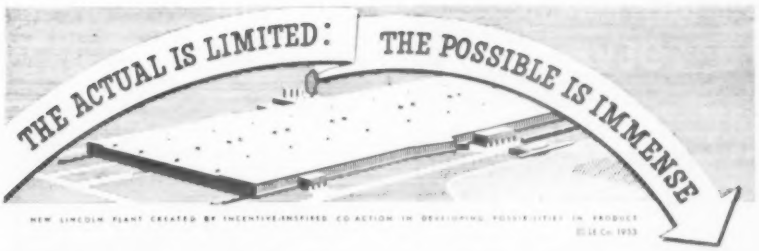


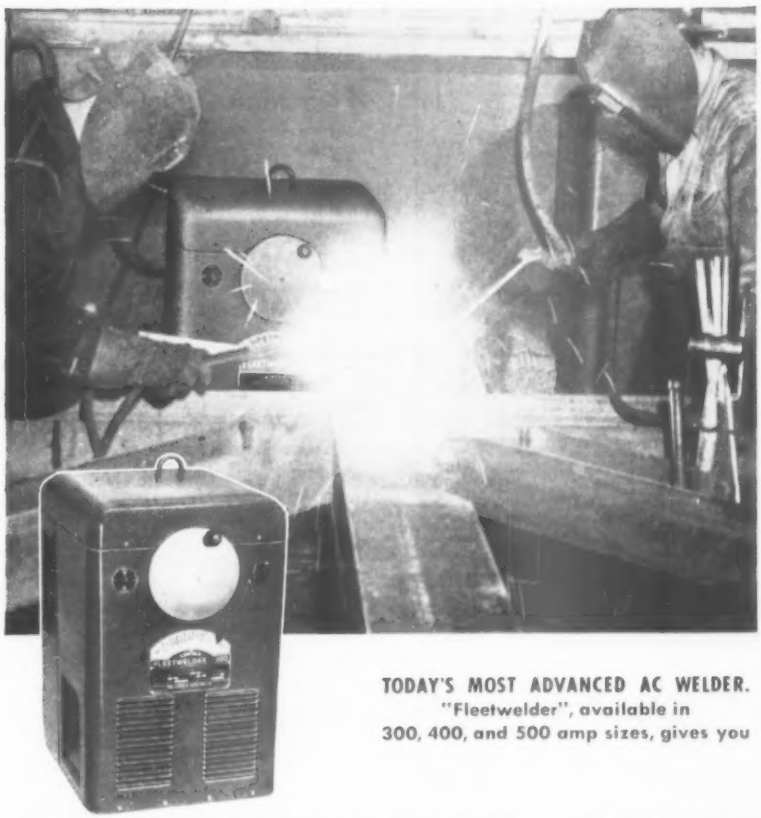
NO CRANKS — NO PUSH BUTTONS

MODEL 21 (shown) SUPER GEAR DRIVEN POSITIONER with powered rotation tilt and elevation.
MODEL X-21 Powered rotation, ball bearing manual tilt and elevation.
MODEL 21-P Powered rotation and tilt, ball bearing manual elevation.
MODEL 21-E Powered rotation and elevation, ball bearing manual tilt.
MODEL X-21-PE Powered rotation, tilt and elevation. 5000 capacity @ 6" CG location.

Aronson MACHINE CO.
MAIN and ARONSON STREETS · ARCADE, NEW YORK

WORK WORK

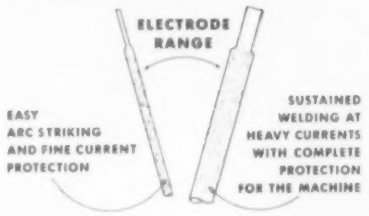




TODAY'S MOST ADVANCED AC WELDER.
"Fleetwelder", available in
300, 400, and 500 amp sizes, gives you

EXTRA RANGE TO SAVE EXTRA DOLLARS
on light and heavy work

LOOK at the sketch. It shows *how* you benefit through "Fleetwelder's" wide current range in which maximum welding currents are 15 times minimum current values.


ELECTRODE RANGE
EASY ARC STRIKING AND FINE CURRENT PROTECTION
SUSTAINED WELDING AT HEAVY CURRENTS WITH COMPLETE PROTECTION FOR THE MACHINE

This *extra range* teamed with "Fleetwelder's" exclusive "Arc-Booster" insures fine currents *with instant arc striking* for light gauge jobs while with the same welder you have ample amps for sustained welding at high currents.

No other AC welder offers this cost cutting combination . . . and at such low cost.

INVESTIGATE "FLEETWELDER" TODAY— See what new advancements in faster, more efficient welding are being put to use by Lincoln to simplify and speed your operations and cut your welding costs.

SEND FOR FREE BULLETIN 1314 *on "Fleetwelder". Available by writing on your letterhead to Dept. 1908.*

THE LINCOLN ELECTRIC COMPANY
CLEVELAND 17, OHIO
THE WORLD'S LARGEST MANUFACTURER OF ARC WELDING EQUIPMENT

11 WAYS to cut AC welding costs

DESIGNED for faster, simpler, more efficient welding, Lincoln's "Fleetwelder" saves money on every AC job. Here's how:

1. SELLS FOR LESS—Built with Lincoln incentive production methods, "Fleetwelders" low selling price gives *more range, longer service, easier, faster operation, greater dependability* for the dollar . . . to cut your AC welding costs.

2. Complete Overload Protection—Built with *generous* reserve capacity for long sustained output at high currents, "Fleetwelder" is *completely protected* against damage due to overheating *by a thermostatic controlled magnetic starter* . . . a feature exclusive with Lincoln.

3. Exclusive "Arc-Booster"—Pioneered by Lincoln, the exclusive "Arc-Booster" blasts the end of the electrode with extra amps for an instant when the electrode touches the work to start the arc automatically. Ideal in out-of-position welding.

4. Completely Safe—No high frequency devices as on some welders to help arc starting. Open circuit voltage is only 71 volts. Output terminal panel recessed to eliminate accidental shorting of leads.

5. "Low Voltage" Safety Relays available for special work. (Optional extra.)

6. Takes Less Power—"Fleetwelder" draws less amps in idle current than required for other AC welders. Inbuilt power factor is higher. Has pilot light to indicate power is on.

7. Low Maintenance—Ventilated from the top, "Fleetwelder" operates cleaner . . . needs less attention. Coils are permanently anchored, cannot become loosened to wear the insulation and short out. Easy accessibility to all working parts.

8. Current Stays Set—Once set, current settings do not change . . . are "locked" in position by rugged drum type holding devices. Illuminated dial shows setting of welding current.

9. Steady Arc—"Fleetwelder's" reactor control is a free circuit designed for high responsiveness to changing arc conditions.

10. Compact, Portable—Only 35″ high, 22″ x 26″ at base, "Fleetwelder" requires less space. Has connection for simple hookup to 220 or 440 volt line. Can be furnished with three wheel undercarriage for moving around the shop.

11. Instant Penetration—The extra current for arc striking also gives *complete penetration* at once . . . no more cold overlaps or partial penetration at the start of the weld.

LET THE EXPERTS SOLVE YOUR
WORN EQUIPMENT PROBLEMS

Many owners of worn equipment have asked us to help solve their particular rebuilding and repairing problems. In many cases we have been successful in devising methods to put worn equipment (some already on the scrap pile) back to work quickly and economically with applications of . . .

MANGANAL

U.S. Patents 1,876,738—1,947,167—2,021,945
11%-13½% MANGANESE-NICKEL STEEL

These solutions were worked out by experts who have spent a good part of their lives determining the best methods of combating wear from impact and abrasion.

Check YOUR scrap pile or worn equipment and send your problems to us. You may save a lot of money and it won't cost you a cent for the answers. DO IT TODAY!

SEND FOR FREE MANGANAL WALL CHART

STULZ-SICKLES CO.
SOLE PRODUCERS 92 N. J. RAILROAD AVE. NEWARK, N. J.

NEAREST DISTRIBUTOR UPON REQUEST

low-cost pen-and-ink drawing or paper cut-out template. Intricate shapes in heavy steel were precision-cut by this pantograph-type gas-cutting machine.

Other items displayed in the booth included welding and cutting torches, portable gas-cutting machines, arc welding machines and welding supplies and accessories.

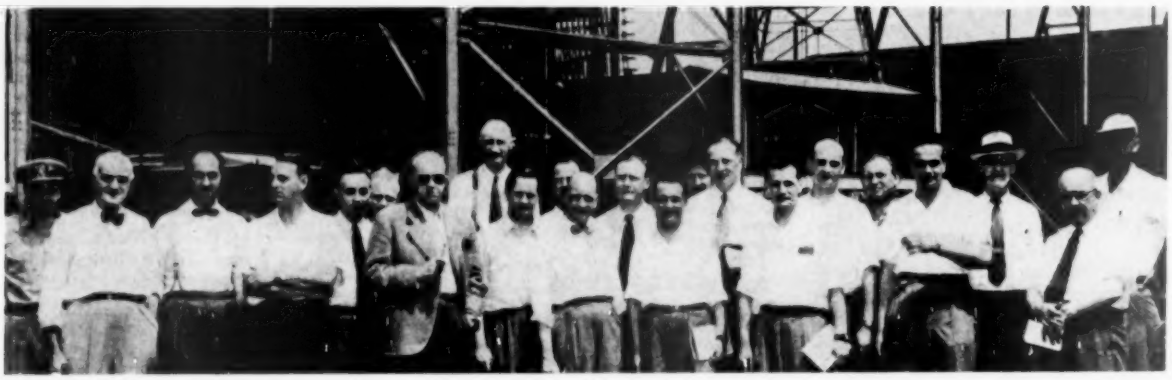
Flame-Hardening Plant

Industries of the Midwest now have at their service the largest flame-hardening plant in this part of the country and the only one in the area to be designed, built and equipped for the sole purpose of applying precision flame hardening and induction hardening to ferrous metals.

This new plant of the Detroit Flame Hardening Co., opened for service on June 1st, is located by 17644 Mt. Elliott, just North of Davison in Detroit; it practically doubles the former capacity of this pioneer firm to serve its many machine fabricating customers in the Central States.

Principles well known to engineers govern the DFH Flame Process. Their successful application, however, requires automatic equipment of special design, broad metallurgical knowledge and experience, and a high degree of manual skill. These the Detroit Flame Hardening Co. is prepared to offer in fullest scope, coupled with the counsel of trained engineers in matters of procedure and design.

European Welding Specialists Visit Ingalls at Pascagoula



A group of European technicians and specialists recently visited the Ingalls Shipyards in Pascagoula, Miss. Pictured above are, left to right, Ensign D. W. Rego, U. S. Navy; Robert R. Bratsch, Project Manager, Mutual Security Agency, Productivity and Technical Assistance Division, Washington, D. C.; John Reginald Thomas, United Kingdom; Svend Walther Lundqvist, Denmark; Armin Erker, Germany; Adolph Luthy, Switzerland; A. Hans Melhardt, Austria; Henri Dutilleul, France; Friederich Wilhelm Griese, Germany; Robert H. Macy, Technical Assistant to President, Ingalls Shipbuilding Corporation; Leslie John Hancock, United Kingdom; Leonard Richard Creasy, United Kingdom; Giovanni Paolo Perego, Italy; Henry Frederick Tremlett, United Kingdom; Willem Gerritsen, Netherlands; Gustave Paul Landragin, France; Karlheinz Speth, Germany; Wilhelm Otto Georg Mantel, Germany; Dr. Karl Kadlez, Austria; Lamott Grover, Welding Engineer, Air Reduction Sales Company; Nicholas Kihn, Luxembourg; Thomas J. Dawson, Metallurgist, Ingalls Shipbuilding Corporation

MORE TIME FOR STEELMAKING... LESS TIME ON REPAIRS

You can keep steel-mill machinery on the job longer by using HAYNES hard-facing alloys to protect wearing parts. With hard-faced parts, you will have less down time and fewer repairs—more time for steelmaking. Illustrated here are some typical savings that have been made.

If you would like a copy of our hard-facing manual, which gives further information on the use of HAYNES hard-facing alloys, fill out the coupon below and mail it to us. For on-the-job help, get in touch with our nearest district office.

1 A yearly application of HAYNES STELLITE alloy No. 1 on this mud-gun screw for blast-furnace tap holes has eliminated monthly maintenance.

2 HAYNES STELLITE alloy No. 6 on the points of soaking-pit tongs has increased their life 19 times. Some hard-faced tongs have lasted as much as 50 times longer than unprotected ones.

3 The life of blooming mill shears has been increased 10 times by applying HASTELLOY alloy C on the cutting edge.

4 Entry guides for a bar-reduction mill used to wear out after handling 40 tons of steel. Guides hard-faced with HAYNES STELLITE alloy No. 6 last 4 to 5 times longer than unprotected ones.

5 Three years ago, some cone rollers in this bar-cooling bed were faced with HAYNES alloy No. 92. They are still in service.

"Haynes," "Haynes Stellite," and "Hastelloy" are trade-marks of Union Carbide and Carbon Corporation.

HAYNES Trade-Mark *alloys*

Haynes Stellite Company
A Division of
Union Carbide and Carbon Corporation
UCC

USE THIS HANDY COUPON

Haynes Stellite Company, 727 S. Lindsay Street, Kokomo, Indiana

Please send me, without obligation, a copy of the booklet, "HAYNES Alloys—Hard-Facing Manual."

NAME_____

COMPANY_____

ADDRESS_____

PERSONNEL

Raymo Joins Fitzgibbons Boiler Co.

Fitzgibbons Boiler Co. has named Arthur J. Raymo, Works Manager of the Oswego, N. Y. plant in an announcement by Paul K. Addams, President.

Mr. Raymo will supervise all phases of production and administration of the Fitzgibbons plant which makes steel heating boilers for all residential and commercial applications and M-47 Military Tank Hulls under a defense production subcontract.

Mr. Raymo comes from the Baldwin-Lima-Hamilton Corp., Eddystone, Pa., where he was most recently Assistant to the Divisional Vice-President.

Albert Muller Made Director

Albert Muller, Manager of the Metallurgical Division, Air Reduction Co., Inc., recently has been appointed Director of Metallurgical Research for the company.

A native of Wading River, N. Y., Dr. Muller received his formal education at the Rensselaer Polytechnic Institute where he obtained his bachelor's and master's degrees in electrical engineering and a Ph.D. in metallurgy. While at RPI he held the International Nickel Co. Research Fellowship in metallurgy. During World War II he was Research Supervisor for the National Academy of Sciences, War Metallurgy Committee. Dr. Muller joined the Air Reduction research laboratories in 1946 as head of the welding section. In 1951 he was made Manager of the Metallurgical Division.

In his new position he is responsible for Air Reduction's research activity in the fields of combustion, physical metallurgy, welding, process metallurgy, instrumentation and thermochemical products.

Dr. Muller is a member of the American Institute of Mining and Metallurgical Engineers, Iron and Steel Institute, Institute of Metals, AMERICAN WELDING SOCIETY, American Ordnance Association and Sigma Xi.

Gramm Made Sales Manager

Appointment of Frank Gramm as Eastern Regional Sales Manager of the Welding Products Division of A. O. Smith Corp. has been announced by J. W. Spoor, General Sales Manager. His headquarters will be in the new Lancaster, Pa.,

electrode manufacturing plant when it is completed this summer. Mr. Gramm was with Lincoln Electric Co. of Cleveland, Ohio, prior to joining A. O. Smith in August 1952.

Lutz Made Manager

Kenneth V. Lutz of St. Louis, Mo., has been appointed General Field Manager of All-State Welding Alloys Co., Inc. Announcement of his promotion was made recently by Bent Laune, President, at the company's offices in White Plains, N. Y.

Mr. Lutz will be responsible for field supervision of sales and service to users and distributors of All-State Alloys and Fluxes, and also for the establishment of additional such facilities when needed. All-State Regional Managers will have his guidance and counsel in solving problems having to do with welding, brazing, soldering, cutting and tinning, and in individualizing for metal workers in their area the help available through All-State's metallurgical resources and experimental laboratory.

Since joining All-State in 1948 and until recently, Mr. Lutz has been Regional Manager for 11 western states and Hawaii. In the past five years he has conducted some 170 All-State clinics and 1600 plant demonstrations. In previous employment he was in charge of sales, demonstrations and technical service on All-State products for Welders Supply Co. in Seattle; shop foreman at Ferrofix Welding and Engineering Co., Seattle; Leadingman Welder, Puget Sound Naval Shipyard; Welding Supervisor, Winslow Marine Shipbuilding Corp., Bainbridge Island, Wash.; and Senior Inspector Ship Construction (welding,) U. S. Bureau of Ships.

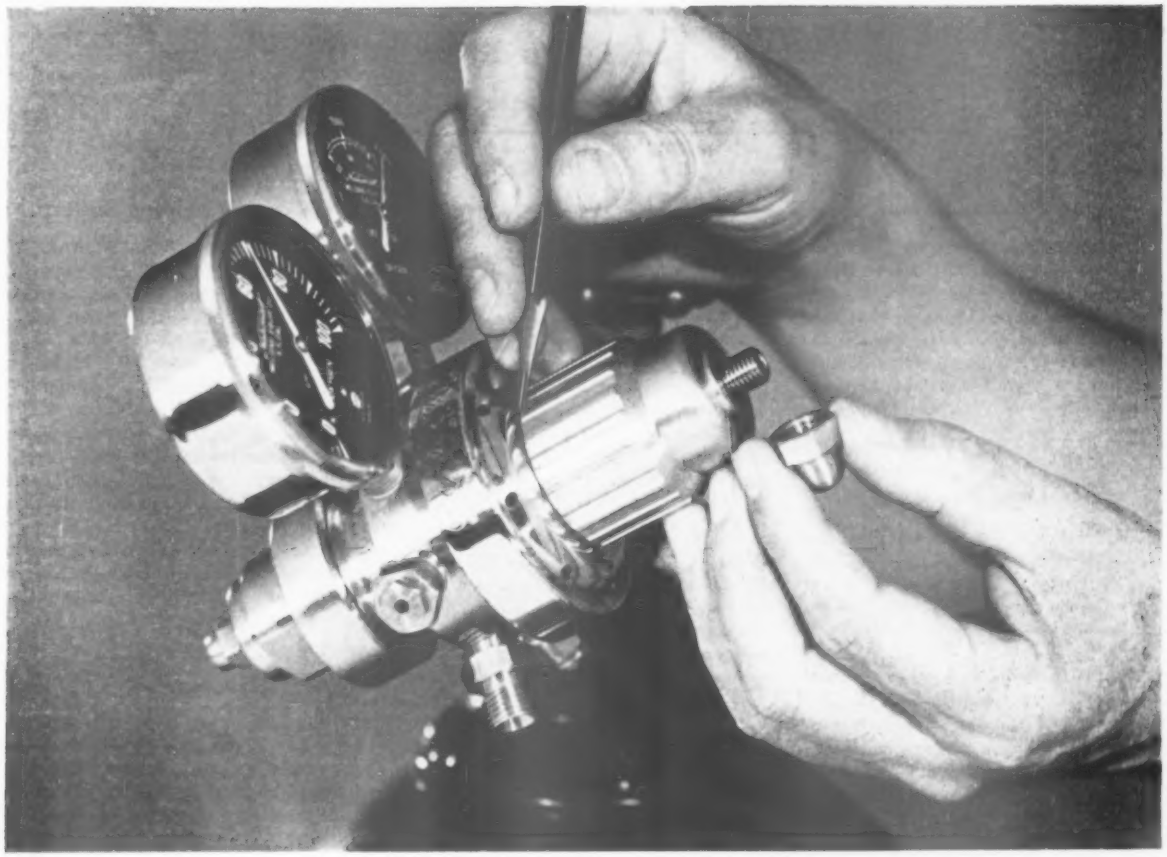
Mr. Lutz completed a course in Welding Engineering at the University of Washington and has been a member of the AMERICAN WELDING SOCIETY since 1940. He had taken up welding in 1935 while in the Navy aboard the battleship U.S.S. *West Virginia*.

H. L. Ingram, Jr., Made Department Manager

H. L. Ingram, Jr., Airco's special representative, Washington, D. C., has been appointed manager of the Technical Development Department of Air Reduction Sales Co., New York, it was announced recently by H. F. Henriques, vice-president. Included in the Technical Development Department are four sections—Aircomatic, Metallurgical, Technical Market Development and Process Development Laboratory.

Mr. Ingram has been with Air Reduction for 18 years. For five years he was with the Applied Engineering Department, another five with the Gas Sales Department and eight years as special representative with offices in Washington, D. C., a post he held until this appointment.

Air Reduction Sales Co., a division of Air Reduction Co., Inc., is a major producer of oxygen, acetylene and welding and cutting equipment.



from "hand-set" to "pre-set" in a jiffy;

and here's how this feature serves you...

Ordinarily, the majority of regulators are *hand set* by the operator. No regulator is as friction free, as easily hand set as is this one. However, where welding or flame cutting mass production operations, or any other valid reason suggests the presetting of a working pressure maximum to save gas consumption or control procedures, this regulator is so designed that it can be *pre-set* instantly . . . and without change of parts or trouble of any kind. Here's how it is done: First set the pressure —loosen the locknut—screw the bell down as far as possible —and refasten the locknut. That's all there is to it—Simple?

A 44 page booklet with 25 illustrations is yours FREE for the asking. Write for it today.

527

Made by **National** **WELDING EQUIPMENT CO.**, San Francisco 5, California

NEW LITERATURE

Flaw Location Booklet

Turco Products, Inc., 6135 S. Central Ave., Los Angeles 1, Calif., has issued an attractive technical pamphlet in color outlining the many applications of dychek and chek-spek. These nondestructive methods are applicable to production line inspection and special applications. Copy of this booklet is available upon request.

Accident Handbook

The National Safety Council's new *Handbook of Accident Prevention for Business and Industry* is a convenient safety guide for the manager of a small business or the supervisor of a department in a large organization.

The handbook shows how to set up and maintain a safety program. Detailed information is included on subjects such as plant layouts, materials handling, housekeeping, machine guarding, electrical hazards, pressure vessel hazards, first aid, fire prevention and personal protective equipment.

The 94-page handbook is profusely illustrated and contains several check lists.

For further information and prices, write the National Safety Council, 425 N. Michigan Ave., Chicago 11, Ill.

Steel Rigid Frames Manual Design and Construction
(170 pages, illus.)

Within recent years the rigid frame has occupied an expanding area in the field of structures. Bulky riveted or bolted connections and details have been superseded largely by trim designs compatible with improved welding and fabrication technique.

Although this text will not be found to be highly theoretical in approach, sufficient fundamental theory is presented to give an adequate concept of the proper analysis and design of this bold, versatile and economical type of framing. The assemblage of basic information, design data and an extensive compilation of current practice adapted for use by the student or the experienced practitioner makes this volume an excellent source book.

Unique in its field, this manual should fill a genuine professional need. The nicely balanced presentation of theory and practice illustrated by an unusual collection of actual designs is commendable. The design tables and other features will aid greatly in developing and stabilizing the judgment of the student and enable the experienced practitioner to design more or less routine structures without resort to laborious calculations.

This book written by Martin P. Korn, M.ASCE, and published by J. W. Edwards, Inc., Ann Arbor, Mich., is 8$^3/_4$ x 11$^3/_8$ in. in size and consists of 170 pages. Price, $4.50 per copy.

Hobart Arc Welding News

Volume X, No. 3, *Hobart Arc Welding News*, a 20-page booklet of interesting photographs and articles on welding from all over North America, is now available. Copies are mailed free of charge to anyone interested in arc welding.

Many of the articles feature time- and money-saving applications. To get your copy, write the Hobart Brothers Co., Troy, Ohio.

WelDesign

A complete course for self-study in the WelDesign System of creating low-cost machine designs in steel includes: (1) manual that outlines system step-by-step giving data, charts, nomographs, tables, cost calculator, process selection guides and time charts; (2) self-study supplementary notes; (3) WelDesign cost calculator slide rule; (4) moment of inertia rule; (5) set of weld standards on onion skin for duplication; (6) copy of the 1300-page *Procedure Handbook of Arc Welding Design and Practice*. Price $10, postpaid in U. S. A.; $12 elsewhere. Publishers, The Lincoln Electric Co., Cleveland, Ohio.

The material now available for complete self-study consists of a large WelDesign manual of factual data to guide engineers in the field of welded design. It covers the inherent qualities of steel as a material and the properties of weld metal. It develops the WelDesign System step-by-step to instruct how to create a steel design. The System goes one step further than is normally considered in design and makes a unique contribution to design literature in that it explains how the designer can and must modify his design for economical manufacture. The manual provides information which is a guide to the correct and effective use of welding to minimize the cost of welding. Suggestions for manufacturing with a welding department are also included.

Resistance Welding Bulletin

Sciaky Bros., Inc., 4915 W. 67th St., Chicago, Ill., has issued Vol. 3, Bull. No. 6, *Resistance Welding at Work*, covering the case history of Sciaky electric resistance welding equipment as used at Day & Night Mfg. Co., Monrovia, Calif., a subsidiary of Affiliated Gas Equipment, Inc.

This case history is an interesting example of electric resistance welding to rigid Government and aircraft specifications for external aircraft fuel tanks for the Northrop Scorpion.

Not only are fine examples of electric resistance welding pictures shown, but several very interesting techniques for seam welding are described.

Hard Surfacing

The Lincoln Electric Co., Cleveland 17, Ohio, has published a technical bulletin No. 466 entitled *Weldirectory for Hard Surfacing*. This gives complete theoretical and practical information on hard surfacing including one entirely new chart entitled "Hard Surfacing Guide." Copies may be obtained on request. The bulletin occupies 20 pages JOURNAL size.

Metal Hose Catalog

Titeflex helically wound flexible metal hose and Uniflex helically corrugated flexible metal hose are illustrated and described in Catalogue No. 200 just published by Titeflex, Inc., Newark, N. J. In addition to complete descriptions and specifications for flexible metal hose, fittings and assemblies, the catalog contains information for ordering Titeflex flexible metal conduit and ferrules, Uniflex hose assemblies, ignition shielding and components for reciprocating engines, Titeflex bendable pipe and Titeflex high- and low-frequency leads.

Bibliography of Resistance Welding

This Bibliography has been prepared to present, as nearly as possible, a complete and accurate record of published technical articles on all phases of resistance welding within the past few years.

This Bibliography, known as RWMA Bulletin No. 17, is available at the Headquarters of the Resistance Welder Manufacturers Assn., 1900 Arch St., Philadelphia 3, Pa. at $1.25 per copy.

Piping and Tube Brazing

Handy & Harman has issued Bulletin No. 61 giving some interesting technical data and illustrations on low-temperature brazing of piping and tubing joints. Copy available on request from Handy & Harman, 82 Fulton St., New York 38, N. Y.

Inert-Gas Metal-Arc Welding

An 8-page reprint, entitled *Will Inert-Gas Metal-Arc Save Money on Mild Steel?*, is being offered by Air Reduction Sales Co.

Reprinted from *The Welding Engineer* and authored by G. C. Christopher and R. C. Becker of the Research Laboratories of International Harvester Co., Chicago, this article reports the results of weld tests on mild steel with the inert-gas metal-arc welding method. Air Reduction engineers assisted in the preparation of this material.

The welding data accumulated from these tests are recorded in tables which show costs as compared to the conventional method of welding mild steel. Graphs and cross-section photos of weld deposits round out the article.

Request your copy by writing Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Stainless Steels

A new bulletin on the welding and metallurgical aspects of stainless steels has been announced as available from the General Electric Co., Schenectady 5, N. Y.

The 8-page publication, designated GET-1955, serves as a practical guide to better practices and results when arc welding stainless steels. It covers the three classifications of stainless steels: martensitic, ferritic and austenitic.

The fully illustrated booklet was authored by W. G. Blackwell of the G-E Welding Department.

Preheat Calculator

Calculator using slide rule principle to quickly determine preheat temperature required when welding hardenable steels. Reissued and brought up to date with latest practice. Calculates preheat in simple steps based on chemical analysis and thickness of steel. Durable construction, easy-to-read figures, price 50 cents in USA; 75 cents elsewhere. Lincoln Electric Co., Cleveland 17, Ohio.

This calculator uses slide rule principles to permit quick and accurate calculation of the preheat and interpass temperature required when the hardening or cracking tendency of metal being welded can be minimized by preheating.

Experience indicates that in some cases best quality welds in high-carbon and some alloy steels are obtained by using preheat. The amount of preheat will vary depending on the chemical analysis of the metal and the thickness.

Corrosion Pamphlet

For 27 years, continuous laboratory research and field study of the nature of corrosive attack on copper and copper alloys have been conducted by The American Brass Co.'s technical staff. The results of this study have recently been brought up to date in a new 28-page booklet, *Corrosion Resistance of Copper and Copper Alloys*. This publication, first of its kind in the industry, explains the chemical and physical nature of corrosive attack in its various forms.

Included is a tabulation indicating the relative corrosion resistance of the principal types of copper and copper-base alloys when in contact with 183 different corroding agents.

This booklet, Publication B-36R, is available without charge from The American Brass Co., Waterbury 20, Conn.

THE SYMBOL OF

QUALITY WELDS

WIRE FOR WELDING
- STAINLESS STEELS
- ALLOY STEELS
- ALUMINUM
- BRONZES
- SPECIAL ALLOYS

WELDSPOOL
the ONLY chemically processed precision spooled electrode wire designed and suitable for ALL TYPES—ALL MAKES inert gas welding equipment

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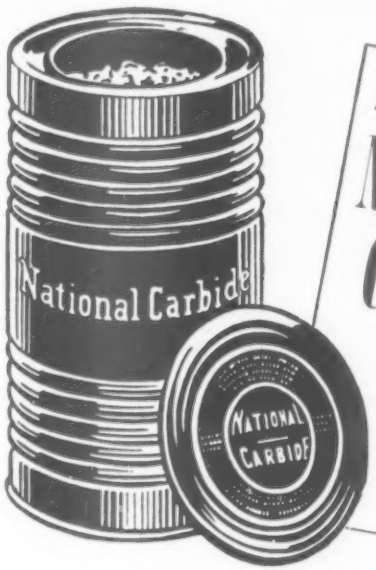

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Since 1919, the American Welding Society has exerted a constant influence for the betterment of welding processes through research and exchanges of experience within its membership. Many of the 8,428 men in A.W.S. are leaders in their respective industries today because of training and encouragement they have received from other "Men of Welding" in the Society.

A.W.S. builds "Men of Welding"

YOUR COMPANY CAN PARTICIPATE THROUGH A SUSTAINING OR SUPPORTING MEMBERSHIP. GET THE FACTS ABOUT A.W.S.

There are 66 active local sections of A.W.S. covering almost every part of the United States. They hold monthly technical meetings and plant visitations. They bring together the best welding minds of the nation and present accurate information on Welding design, fabrication and maintenance. You will profit from A.W.S. membership.

AMERICAN WELDING SOCIETY
33 W. 39th St. New York 18, N. Y.

Please send me more information on advantages of membership in the American Welding Society

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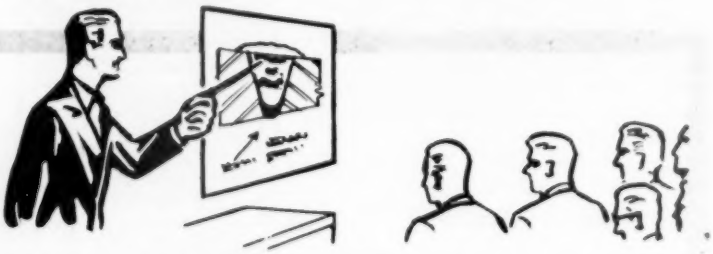

*MEN OF WELDING" ADVANCE IN THEIR PROFESSION THROUGH TECHNICAL MEETINGS AND GROUP DISCUSSIONS ON WELDING METHODS AND PRACTICES.

American Welding Society

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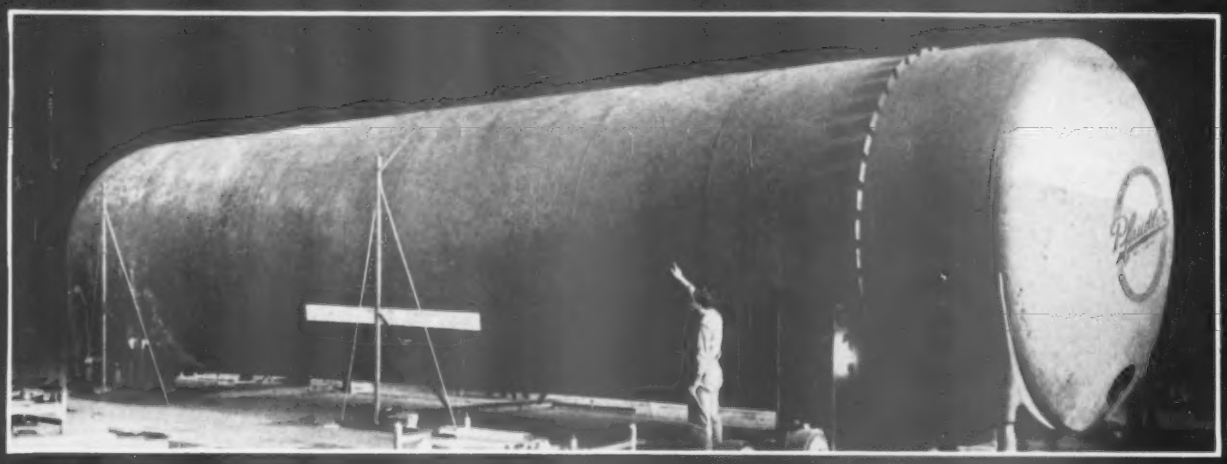
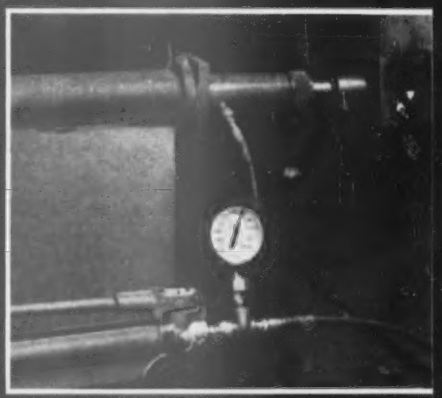


Welded, glassed steel tank 12′ x 54′; capacity 1426 barrels.

Radiography helps protect the quality in 1,000,000 GLASSES OF BREW



Sound welds enable tank's legs to withstand 30,000 p.s.i. thrust test.

THIS GIANT glassed steel tank will store beer to fill one million glasses . . . store it safely and protect its quality in storage.

Thanks to radiography, its seams are sound, expertly welded to accept a lasting bond between steel and glass liner.

Thanks to radiography, its welded legs are sturdy—tested to withstand 30,000 p.s.i. That's 70% in excess of the code requirements in far western earthquake areas.

All this points up two important ways that radiography helps extend the use of welding: It helps to check and to develop welding skills and technics; it proves welds sound.

Radiography can help you get more business—build a reputation for high quality work. If you would like to know how, talk it over with your x-ray dealer.

EASTMAN KODAK COMPANY
X-ray Division, Rochester 4, N. Y.

Radiography . . .

another important function of photography

Kodak
TRADE-MARK

You asked for it ...and..

YOU ASKED FOR...	miller GIVES YOU...
1 Wide current range for all types of welding from the thinnest gauge metal weldable to the maximum capacity of each welder.	1 Unprecedented current ranges ie; SR-200 (3-300 AMPS) SR-300 (3-400 AMPS) SR-400 (5-525 AMPS) SR-600 (125-750 AMPS).
2 Crater elimination.	2 Hand or foot remote control units permit crater elimination and micrometer amperage selection.
3 Range switching from convenience standpoint with simplified current control.	3 A new, conveniently located range selector switch and dual "Unitized" infinite current controls.
4 Instantaneous, convenient polarity reversal.	4 New, rugged MILLER designed polarity reversal switch.
5 High weld deposit rate.	5 *Time tested pulsating direct current due to MILLER'S unique electrical circuit.
6 Greater arc flexibility throughout entire welding range.	6 Magnetic amplifier circuit and new current stabilizing coils insure complete arc stability at all current settings.
7 Guaranteed rectifier performance.	7 Rectifiers specially designed for welding applications, thermostatically protected and warranted under a 5 year guarantee.
8 The BEST D. C. Arc Welder.	8 The new MILLER SR Welders—raising the standards for D. C. welding to a new high.

*Patented and patent applied for.

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...here it is!

the NEW miller SR WELDER

4 Models — from 200 AMP to 600 AMP.

ARC SPOT miller GENERATORS WELDERS

Following the familiar pattern of always leading the field in new developments and advanced design, MILLER scores again with the new SR.

Incorporating ideas gained from extensive research and your field experience, the new MILLER SR welders represent the ultimate in D. C. welding.

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Why not get the complete story on the new SR welders . . . today!

See your MILLER distributor.

MANUFACTURING CO. APPLETON WISCONSIN

NEW PRODUCTS

Welder

To meet the requirements for a compact 50% duty cycle welder with an unusually wide range of current adjustments is the new moving coil transformer type industrial welder manufactured by Miller Electric Manufacturing Co., Appleton, Wis. Designated as Model 99, it has a rated output of 250 amp at 30 arc volts with a top usable output of 350 amp. Its two open-circuit volts, on different ranges, make it flexible in all applications with the higher open-current voltage satisfactory for utilization of "low-hydrogen" electrodes. A new compact design that uses

air-spaced primary and secondary coils wound with high-quality double-glass-covered insulated wire assures trouble-free long life. Time-proved, continuous current control, using the moving coil principle, produces a smooth easy-to-handle flexible welding arc. Operation from either 220- or 440-v, 60-cycle single-phase lines is standard. Simple and foolproof current adjustment with the new "easy-to-read" current scale is another feature. Current settings can be duplicated quickly and positively. Its low cost plus high electrical efficiency places this new welder high in arc welder values.

IPCO Fog-Free

Industrial Products Co. announces a new antifog liquid for use on glass and plastic surfaces where fogging and steaming presents a problem.

Fog-Free is packaged in 4-oz. "squeeze-spray" plastic bottles—easy to use and economical. A drop is all that is necessary on each spectacle lens—a quick spray to larger surfaces—quickly spread and wiped dry with a clean cloth or tissue.

Complete information may be obtained by writing to Industrial Products Co., 2832 N. Fourth St., Philadelphia 33, Pa.

Bronze Electrode

Aluminum bronze coated electrodes—Albronze 100, Albronze 200 and Albronze 250—depositing weld metal with Brinell hardness, respectively, of about 100, 200 and 250 are available.

The recommended amperages for these electrodes are as follows:

Size, in.	*Current, amp*
3/32	45–70
1/8	75–110
5/32	95–135
3/16	110–160

Also precision spooled aluminum bronze wire for gas-shielded metal-arc welding.

Data sheets on request from Weldwire Co., Inc., N. W. Corner Emerald and Hagert Sts., Philadelphia 25, Pa.

Fogging of Welding Goggles

An entirely new ventilation principle has been developed to provide welding goggles that will not steam up or fog even in hot, damp weather. Like the windshield defroster in a modern automobile, the new OXWELD No. 24 Coverall Goggles depend upon a steady stream of air to prevent steaming and moisture condensation. Sixteen vents, located behind the lens-retaining rings, permit continuous circulation of fresh air across the inside surface of the lenses.

The goggles, introduced by Linde Air Products Co., a Division of Union Carbide and Carbon Corp., are designed to fit comfortably over any spectacle frame—to provide comfort and safety to the operator who must wear corrective eyeglasses while welding or cutting. They are adjustable for broad or narrow features so that every wearer can look through the center of the lenses without "seeing the frames."

Flame-resistant, high-impact nylon is used for the frames. A metal bar across the top of the eyecups holds them rigid, so that the goggles can be raised or lowered conveniently with one hand. They are green and come equipped with standard "AA" type lenses.

Spot-Gun Welder

Almost revolutionary in the field of welding is a new Spot-Gun Welder from Great Britain. Looking like a small submachine gun and held in much the same manner, it does all types of on-the-spot jobs ranging from spot welding of auto bodies, aircraft repairs, shipyard repairs, sheet metal working, the preliminary tacking or welding of large sheet metal assemblies, and other work not usually possible with stationary spot welders.

Its extreme portability and light weight (only 25 lb) give this well-engineered product a decided advantage over other welding equipment. There are only two movements required, i.e., squeezing of the toggle grip to obtain high forging pressure at the tips, and the simple depression of a trigger switch to produce a perfect spot weld in a fraction of a second. The toggle grip provides excellent balance for manipulating the gun with three-point suspension—a most important, but often overlooked feature—which makes it possible to handle this portable spot welder with the minimum of operator fatigue. A simple squeeze with the fingers of the left

hand, which is already positioning the Spot-Gun, produces a working tip pressure unusually high for this class of tool. It will weld a maximum combined thickness of 0.16 in. with the short arms. No condenser is required. A further feature is that glass insulation protects the operator.

Each Spot-Gun is supplied in a strong fitted case, fully complete with a range of nine assorted heavy copper extension arms and two clamps, which make it possible for various combinations to be built up so that spot welding can be produced at different angles, and in difficult positions, with reaches from 5 to 24 in. Manufactured by Triangle Products Ltd. of Manchester, England. U. S. commercial representative is C. F. Carpenter, Allentown, Pa.

Automatic Heliweld Hardfacing Unit

An Automatic Heliweld Hardfacing Unit, a new development by Air Reduction, grew out of a need for improved methods in depositing tungsten carbide hard-facing material on tool joints for well-drilling rigs. It uses the standard Automatic Heliweld Head and a unit for feeding the bulk tungsten carbide. The flexibility of this unit has been proved by numerous tests which show that its use for the deposition of tungsten carbide hard-facing material is limited only by the ability to position the work and the arc in the proper relationship to each other.

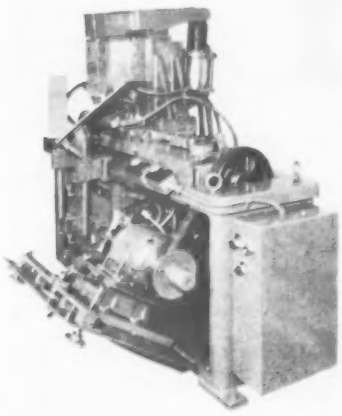
The manner of deposition of loose, granular, pure tungsten carbide particles minimizes reduction of particle size by solution of the tungsten carbide into the base metal. It also minimizes the heat-affected area adjacent to the deposit.

In operation, the Heliweld arc melts the base metal, producing an elongated pool and the tungsten carbide particles are poured into this pool behind the arc. The rate of tungsten carbide feed from the Vibratory Hopper mounted on the Automatic Heliweld Head is electrically controlled with a high degree of accuracy.

Tests have shown that the abrasion resistance of deposits made by this process is considerably greater than that attainable with other arc methods.

Flash Welder Improvement

Reduction of inertia forces in the gearing to the offset cam on a precision flash-butt welder has been accomplished by the use of double-enveloping worm gearing. This gearing (produced by Cone-Drive Gears, Division of Michigan Tool Co., Detroit) is characterized by having greater contact per tooth and more teeth in contact, enabling the use of smaller gears to handle the same amount of power. In addition, the large number of teeth in contact provide an action even smoother than that of an hydraulic system, it is said. Precision Welder & Flexopress Corp., Cincinnati 10, Ohio, incorporated in their flash welder a standard speed reducer, eliminating large bulky gear trains with their high inertia forces. Gears not only get moving faster but also slow down quicker when the power is removed. The Precision Welder is shown here tooled for the production of automobile garnish moldings. The front panel is open showing the accessibility of motor drive and brake for ease of maintenance.



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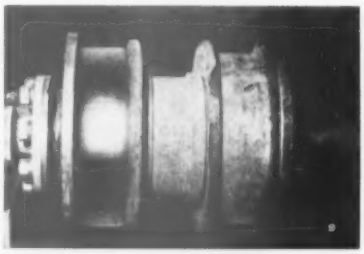
GOOD
build-up results . . .



specify
REXARC "S-3"

- Recommended for rebuilding crawler type tractor parts, crushers, hammers, bucket lips and dozens of other applications.
- Metallic coating assures maximum deposit of weld metal. This means Rexarc is the least expensive electrode on the market, regardless of price per pound.
- An all-position electrode. Applys equally well on AC or DC.
- Easiest build-up electrode on the market to apply. Exceptionally quiet arc.
- Deposits absorb extreme shock, resistant abrasion. Outwears new parts 3 to 10 times.

For further information, see your Welding Supply Distributor or Write

SIGHT FEED
GENERATOR COMPANY
WEST ALEXANDRIA, OHIO, U.S.A.

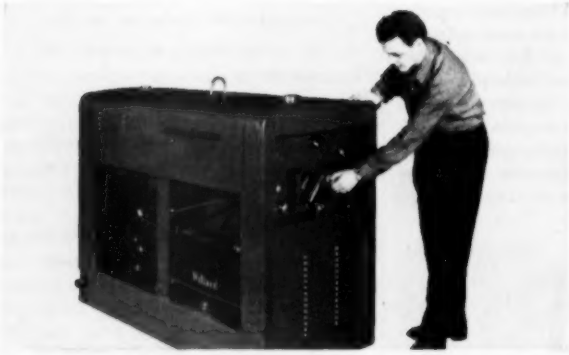
Welding Arcs

G-E MG WELDERS—half the size of other d-c welders of this type—offer a steady-arc interactor, single-dial dual control, easy inspection, wide current range, and high efficiency, for high production, operator satisfaction, low operating costs.

G-E AC WELDERS—best for 3 out of 4 jobs because of no arc blow—feature instant arc striking, steady capacitor-stabilized arc, exact current setting on the easy-to-read scale, high power factor for low-cost operation, and long-life silicone insulation.

FOR AC OR DC

Top performance, low over-all cost make G-E welders your best buy



G-E ENGINE-DRIVEN WELDERS—5 rugged types for every outdoor job—are powered by leading air- and liquid-cooled gasoline engines and diesels. Sturdily built to stand up in outdoor service, these units provide excellent welding performance.

Whatever the requirements of your welding job—whether it's AC or DC, indoors or outdoors—there's a General Electric welder available to give you unsurpassed performance. The features and operating benefits listed on this page can mean real savings for you during the long life of your G-E equipment.

You get more than just quality equipment when you buy G.E. Prompt shipment, application help, and complete service facilities provided by your local G-E Welding Distributor mean extra dollar savings for you.

For complete information on G-E welders and how they can help you do a better job at lower cost, contact your nearest G-E Welding Distributor today. He's listed here and in the classified section of your phone book under "Welding Equipment". General Electric Company, Schenectady 5, New York. 710-5

You can put your confidence in—

GENERAL ELECTRIC

News

Information on equipment, electrodes and accessories from G.E., pioneer in arc welding

New G-E electrode nomenclature will simplify selection, stocking, training

To simplify electrode selection, stocking, and training, which have been complicated by the large variety of electrodes manufactured today, General Electric has put into effect a new mild-steel and low-alloy electrode nomenclature system. This new system, closely tied to familiar AWS classifications, can be explained by a simple example:

The G-E electrode formerly known as W-28 is an AWS Class E-6012 electrode. Under the new G-E system, this electrode will be known as W-612A, formed by adding "W" to the basic 6012 and, for simplicity, dropping the "0". The "A" is used to differentiate between this electrode and two other Class E-6012 electrodes (formerly W-29 and W-20F) which will now be termed W-612B and W-612C. All other G-E mild-steel and low-alloy electrodes will be designated in a like manner.

During changeover to the new system, G-E electrode packages will carry both old and new numbers. Nomenclature of G-E stainless-steel and hard-surfacing electrodes will not be altered.

To familiarize yourself with the new G-E electrode nomenclature, ask your G-E Welding Distributor for a copy of GED-1634A.

Copyright 1953, G.E. Company

Joe Magee says . . .

New W-610A electrodes reported 8 ways better

User reports on General Electric's new W-610A electrode list 8 performance benefits of this outstanding Class E-6010 rod.

They say W-610A . . .

- is easier, faster to use
- is free of "wandering arc"
- eliminates pinholing problems
- produces lower-porosity welds
- stops "fingernailing"
- has a stable coating
- prevents excessive spatter
- makes slag removal easy

Find out for yourself

If you haven't discovered these benefits for yourself, contact your General Electric Welding Distributor today. He'll give you a free sample of G-E Type W-610A—the electrode that's fast becoming the quality standard for the welding industry.

FREE

Stainless-steel Guide

If you weld stainless steel, you'll want this new G-E Bulletin "Welding and Metallurgical Aspects of Stainless Steels". Written for both the novice and veteran weldor, this easy-to-read pamphlet is full of practical data to help you select electrodes, produce better welds, and avoid common problems in stainless-steel work. Ask your G-E Welding Distributor for Bulletin GET-1955.

Here's the name of your G-E Welding Distributor—

Alabama: Birmingham—Alabama Oxygen, Young & Vann Supply; Mobile—Turner Supply

Arizona: Phoenix—Consolidated Welding Supply

California: Fresno, Los Angeles, Oakland, Sacramento, San Diego, San Francisco, Ventura—Victor Equipment

Colorado: Boulder, Colorado Springs, Denver, Durango, Ft. Collins, Ft. Morgan, Greeley, LaJunta, Longmont, Pueblo—Hendrie & Bolthoff

Florida: Hollywood, Miami—Florida Gas & Chemical

Georgia: Atlanta, Macon—Welding Supply & Service; Augusta—Marks Oxygen; Columbus—Williams Welding Supplies

Idaho: Boise—Olson Manufacturing

Illinois: Chicago, Moline, Morton—Machinery & Welder

Indiana: Evansville—Drill Master Supply; Ft. Wayne, Indianapolis—Sutton-Garten; South Bend—Perry Welding Sales & Service

Iowa: Des Moines—Machinery & Welder

Kansas: Coffeyville—Thompson Bros. Supply & Welding Equip.; Hutchinson—Kopper Supply

Kentucky: Louisville—Reliable Welding; Paducah—Henry A. Petter Supply

Louisiana: Alexandria, Shreveport—Hughes Oxygen; New Orleans—Consolidated Welding Supplies

Maryland: Baltimore—Arcway Equipment

Massachusetts: Boston—New England G-E Welding Sales Division

Michigan: Detroit—Welding Sales & Engineering; Grand Rapids—Miller Welding Supply

Minnesota: Duluth—W.P.&R.S. Mars; St. Paul—Production Materials

Mississippi: Jackson—Jackson Welding & Supply

Missouri: Kansas City—Hohenschild Welders Supply; St. Louis—Machinery & Welder

Montana: Billings—Valley Welders Supply; Butte, Great Falls—Montana Hardware

Nebraska: Lincoln—Lincoln Welding & Supply; Omaha—Baum Iron

New Jersey: Kenilworth—Welding Sales

New Mexico: Albuquerque—Industrial Supply Co., Hobbs—Western Oxygen; Las Cruces, Silver City—Car Parts Depot, Inc.

New York: Buffalo—Welding Equipment Sales; Syracuse—Welding Engineering & Equip.

North Carolina: Charlotte—Dixie Gases; Gastonia—Gastonia Motor Parts

North Dakota: Bismarck, Fargo—Acme Welding Supply; Fargo—Dakota Electric Supply

Ohio: Akron, Cincinnati, Cleveland, Columbus, Dayton, Mansfield—Burdett Oxygen; Toledo—Odland Iron Works

Oklahoma: Tulsa—G-E Welding Sales Division

Oregon: Eugene, Portland—J. E. Haseltine; Medford, Portland—Industrial Air Products

Pennsylvania: Philadelphia, Pittsburgh—Arcway Equipment

South Carolina: Columbia, Greenville—Welding Gas Products

South Dakota: Deadwood—Hendrie & Bolthoff

Tennessee: Chattanooga, Knoxville, Nashville—Welding Gas Products; Memphis—Delta Oxygen

Texas: Abilene—M&M Welding Supply; Alice, Corpus Christi—Crane Welding Supply; Alpine, El Paso, Marfa, Pecos—Car Parts Depot; Amarillo—Tex-Air Gas; Brownsville, Harlingen—Acetylene Oxygen; Dallas—Hill Equipment & Supply; Hereford—Tex-Air Gas; Houston—G-E Welding Sales Division; Lubbock—Welders Supply of Lubbock; Midland—West Texas Welders Supply; Odessa, Pecos—Western Oxygen; Plainview—Plains Welding Supply; San Angelo—Southwestern Welding Supply; Snyder—Western Welding Supply; Texarkana—Hughes Oxygen; Wichita Falls—Nortex Welding Supply

Utah: Salt Lake City—The Galigher Co.

Washington: Seattle, Spokane—J. E. Haseltine; Spokane, Yakima—Industrial Air Products

West Virginia: Bluefield—Bluefield Supply; Charleston—Virginian Electric; Huntington, Logan—Logan Hardware & Supply

Wisconsin: Milwaukee—Machinery & Welder

Alaska: Anchorage—Northern Supply

Canada: Toronto—Canadian G.E.

Hawaii: Honolulu—American Factors, Ltd.

Reducing a 12 day cutting job to 2 days with the ARCAIR TORCH

ARCAIR cut labor costs more than 80% on a recent job for Seidelhuber Iron & Bronze Works of Seattle, Wash., removing mild steel welds in one-sixth the time required with a chipper.

A change in requirements on three steel trash racks being built for McNary Dam left Seidelhuber with the job of removing 167 cross members on each rack. These cross pieces were triple welded with $4^1/_2$-inch double fillet welds.

Two men with a chipper took three full days to strip one rack, plus the help of an extra man sharpening chisels. The remaining two racks were stripped by one man using an ARCAIR Torch. The job was completed in two days at a labor saving of 80 man-hours.

In addition to the time saved in actual removal of the welds, the job done by the ARCAIR Torch required far less grinding to prepare the surface for re-welding. The ARCAIR method slashed operating costs too.... expenses amounted to $8 worth of electrodes plus the operation of a welding machine and air compressor.

Said the leadman on the job, "The Arcair torch is faster than any other method I know of for leaving a smooth surface with little grinding. It's worth the expense even for one job."

Write for free bulletin with facts and photographs of other time and money saving applications of the Arcair Torch.

There is an authorized Arcair dealer near you who will arrange for a demonstration in your plant. Arcair Company, *Eastern Division:* 423 S. Mt. Pleasant St., Lancaster, Ohio. *Western Division:* P.O. Box 4107, Bremerton, Wash.

Arcair TORCH

Cuts all metals—using only electric arc and compressed air

nance. The reducer has a center distance of only 3 in. to transmit the power from a 1-hp motor.

Heavy-Duty Heliarc Torch

Continuous heavy-duty inert-gas arc welding at 500 amp is possible with the new water-cooled Heliarc HW-12 torch. Currents of all types—Direct-Current Straight Polarity, Direct-Current Reversed Polarity and Alternating Current with High Frequency—can be used to weld practically all commercial metals. It also can be used for hard-facing operations.

The HW-12 was recently developed by Linde Air Products Co., a Division of Union Carbide and Carbon Corp. It has an improved water-cooling system that allows uninterrupted service at the full-rated capacity of 500 amp without overheating. (Higher currents are possible with reduced duty cycles.) The cooling water flows into the torch body and down around the water jacket housing the gas cup. The return flow leaves the torch body through a plastic hose housing the power cable. All external "plumbing" has been eliminated which prevents leakage from accidental damage and allows more maneuverability. Water cooling makes lightweight torch construction possible, and because the power cable is also water cooled, it, too, is lightweight and easy to handle

The torch is readily disassembled and because all internal water flow passages are straight, cleaning is an easy matter even in "hard" water districts where lime deposits are usually a problem.

The entire torch body is sheathed in tough, heat-resistant plastic. It requires no additional asbestos shielding to prevent melting due to reflected heat.

See your local Linde office for more in-

New Heliarc torch has a rated capacity of 500 amp for continuous service

SINGLE POINT • AIR OPERATED
PEDESTAL TYPE
MODELS WM-629 • WM-680
SPOT WELDERS

"THE STRONGEST IN YOUR PRODUCTION CHAIN"

WM-629 SPECIFICATIONS

TRANSFORMER: 220 or 440 volt primary as specified; 3.19 minimum to 5.0 maximum secondary voltage. Four Point Dial Type Heat Selector Switch, mounted for outside adjustment. Water-cooled secondaries.

ARMS: 2½" dia., mounted in heavily ribbed copper castings, equipped with standard water-cooled 1" dia. point holders.

THROAT: 12" to 18", stroke, 3".

OPERATION: 3" dia. air cylinder. ⅜" four-way solenoid air valve operated through foot switch.

FRAME: All-welded steel construction. 60" high, 25" wide, 25" long.

SHIPPING WEIGHT: 800 lbs.

WM-680 (shown on left) SPECIFICATIONS

CAPACITY: 75 KVA at 50% duty cycle.

TRANSFORMER: 220 or 440 volt primary as specified; 6.6 minimum to 10. maximum secondary voltage. Six Point Dial Type Heat Selector Switch, mounted for outside adjustment. Water-cooled secondaries.

ARMS: 3" dia., mounted in heavily ribbed copper castings. Standard water-cooled 1¼" dia. point holders.

THROAT: 18"; stroke, 3".

OPERATION: 5" dia. air cylinder; ⅜" four-way solenoid air valve operated through foot switch.

FRAME: All-welded steel construction. 70" high, 30" wide, 60" long.

SHIPPING WEIGHT: 1100 lbs.

Note: WM-680 also available with Transformer capacity of 70 KVA at 50% duty cycle; 5.0 minimum to 7.1 maximum secondary voltage. All other specifications as indicated above.

LINK offers the engineering advances that mean ACCURATE, HIGH SPEED WELDING PRODUCTION to you!

Ideal for high speed resistance welding of mild steels in broad variety, these units have features that assure extreme accuracy in volume production. Every Link model is engineered to JIC electrical and air standards. Moderate in original and low in operating cost, these Link Spot Welders will perform dependably for you under any production schedules.

Further technical data available on request. Submit your welding problems to Link Welder. You will receive complete and competent recommendations without obligation to you. Write today.

LINK
"THE STRONGEST IN YOUR PRODUCTION CHAIN"

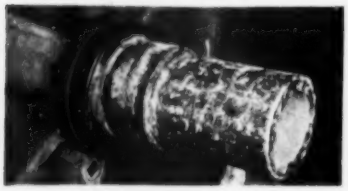
LINK WELDER CORPORATION

Designers and Manufacturers of High Production Welding Equipment

13684 WEST BUENA VISTA • DETROIT 27, MICHIGAN

Build up with...
All-State No. 13 Nickel-Silver ☑
Retemper...
None Required ☐

• Dirt Mover Gears and Pinions • Finely Heat Treated • Reclaimed in 14 hr. with 25 lb. All-State No. 13 • Saved $510. net.



• Steam Processer Packing Gland Journal • None reclaimed before • 20 lb. of All-State No. 13 included in $300. overall repair • Saved replacement at $1300.

• Dripless Ball and Cone Valves • Rejections reduced to zero since adopting All-State No. 13 • High resistance to abrasion and galling is imperative.

All-State No. 13 Nickel-Silver Build-up Rod (and the No. 11 Brazaloy Flux that's always used with it) is sold just about everywhere. Over 600 All-State Distributors have it in stock. Write us for names of those near enough to you to be convenient. Ask for "Steel Booklet" to get complete application instructions.

All-State
ALL-STATE
WELDING ALLOYS CO., INC.
White Plains, N. Y.

formation about this new Heliarc HW-12 inert-gas arc-welding torch or write direct to Linde Air Products Co., 30 E. 42nd St., New York, N. Y.

Wrought Iron Tank

Designed by engineers of the Delaware, Lackawanna & Western Railroad for the "sealed-in" protection of vital operating machinery, this huge tank will be installed below water level at the railroad's Coal Pier No. 5 on the Hudson River, Hoboken, N. J. The big tank is more than

12 ft 6 in. long, almost 10 ft wide and 8 ft deep. It is constructed entirely of $^3/_8$-in. wrought iron plate to protect against damage from corrosion due to salt water and to secure a longer life for the installation. L. O. Koven & Brothers, Inc., fabricated the tank in their own shops in Dover, N. J., where the above picture was taken.

Portable X-ray

Now available is Andrex's new 250-kVp industrial X-ray unit. Like all Andrex units, this one features complete portability. Its overall weight, including the control unit, is less than 350 lb, and the entire unit fits easily into the trunk compartment of a late model automobile. Andrex's small size and light weight are the result of eliminating all high-tension cables, cooling connections, separate transformers and cooling pumps. The X-ray tube and other high-tension parts are combined in a single all-welded steel tank.

This 250-kVp unit will penetrate 4 in. of steel. The focal spot is 4 mm., and at a focus-film distance of 24 in. a 17-in. film is covered. Supply voltages are 110, 220, 440 (50–60 cycles). The Andrex X-ray unit is, incidentally, the only one made, which is able to operate on 110 v.

A unique feature of this Andrex unit is that, due to its radical type of construction, it requires little or no service.

Holger Andreasen, Inc., 703 Market St., San Francisco, Calif.

Hard-Surfacing Electrode

A new welding electrode, designed for build-up work and hard-surfacing applications wherein the deposited metal can be machined or flame hardened, has been announced by the General Electric Co.'s Welding Department.

The new electrode, designated G-E Type W-98, is a heavy-covered flame-hardening rod that can be used in all positions. The arc is of the steady-spray type, similar to that produced by the E-6013 electrode.

The W-98 can be used in build-up work on road machinery parts, gears, pinion teeth, pump housings, shafts, sprockets, ship hawse pipes and so forth. It is recommended where a higher hardness deposit is desired than that obtainable with electrodes used for underlayers.

Although the type of material involved and the welding conditions can greatly

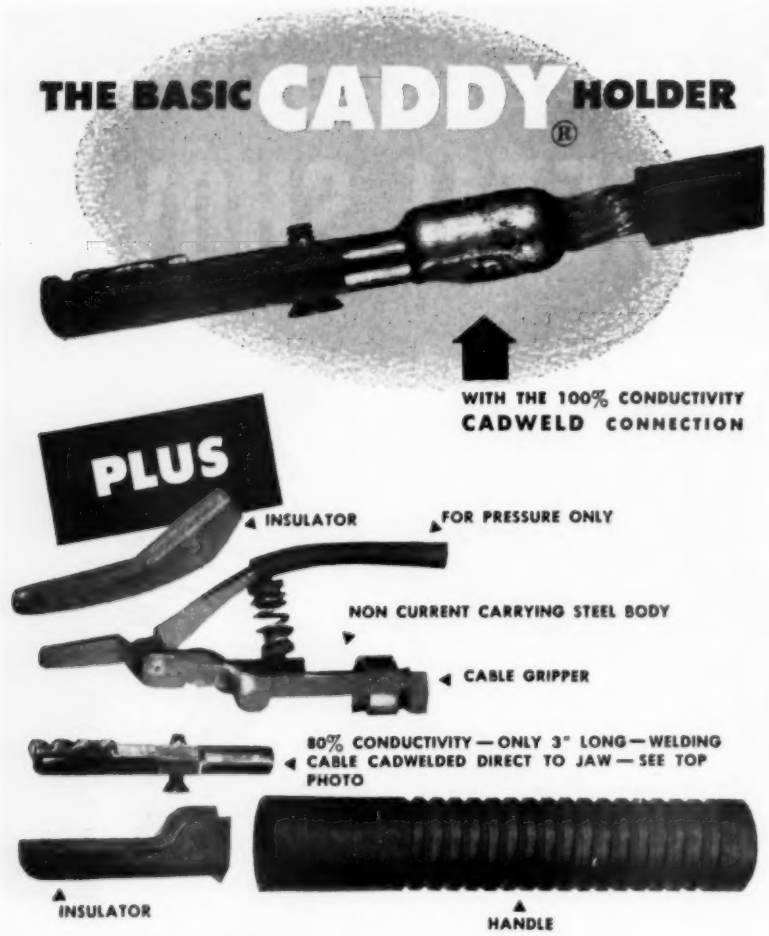
NATIONAL METAL EXPOSITION

THE BIG METAL SHOW

Champion – in the Metals Market Place of the World!

Unmatched anywhere in the world for intensity of interest . . . for wealth of ideas and basic appeal . . . the National Metal Exposition in Cleveland's Public Hall this October, will be host to another record-breaking audience of metals industries people . . . intent upon seeing the newest . . . the finest . . . the most wanted developments America's industrial genius has created. For every man interested in metals, this champion of all industrial expositions offers *more of everything!*

CLEVELAND, OHIO • OCTOBER 19-23


THE BASIC CADDY® HOLDER
WITH THE 100% CONDUCTIVITY CADWELD CONNECTION
PLUS
INSULATOR
FOR PRESSURE ONLY
NON CURRENT CARRYING STEEL BODY
CABLE GRIPPER
80% CONDUCTIVITY — ONLY 3" LONG — WELDING CABLE CADWELDED DIRECT TO JAW — SEE TOP PHOTO
INSULATOR
HANDLE

300 AMP—18 OZ.
400 AMP—19 OZ.
500 AMP—27 OZ.

THE FINEST OPERATING COOLEST HOLDER ON THE MARKET

WRITE FOR CADDY CATALOG TODAY

CADDY

ARC WELDING ACCESSORY DIVISION

ERICO PRODUCTS, INC.

2070 EAST 61st PLACE • CLEVELAND 3, OHIO

affect the hardness of the deposited metal, generally the hardness will be approximately 250 Brinell as welded and it will flame harden to about 350 Brinell.

The new G-E electrode is color marked by a brown end and a white spot. It utilizes alternating or direct current, and is manufactured in $\frac{1}{8}$ to $\frac{1}{4}$-in. sizes.

Toggle Clamps

A catalog sheet giving all the features on the new CADDY V-1, V-2 and V-3 Toggle Clamps has been issued. Erico Products, Inc., 2070 E. 61st Place, Cleveland 3, Ohio, has built a line of rugged heavy-duty clamps that will stand up under production abuse where present riveted toggle clamps fail.

The CADDY Toggle Clamp has been put through numerous destructive tests to eliminate all weak points.

Pressure ratings and dimensions are given for each toggle clamp on the reverse side of the catalog sheet.

Concrete Anchors

Development of special concrete anchor studs designed to simplify fabrication and improve the quality of steel curb angles, trench frames, column guards, joists and other structural members to be anchored in concrete or masonry has been announced by the Nelson Stud Welding Division of Gregory Industries, Inc., Lorain, Ohio.

High-quality, cold-drawn steel with a tensile strength of 75,000–85,000 psi is used in the new fluxed anchor studs which are welded in the angle or on the faces of steel members without causing any distortion. Accessories for use with portable stud welding equipment insure accurate alignment so that work can be done at the job site where necessary. Simple

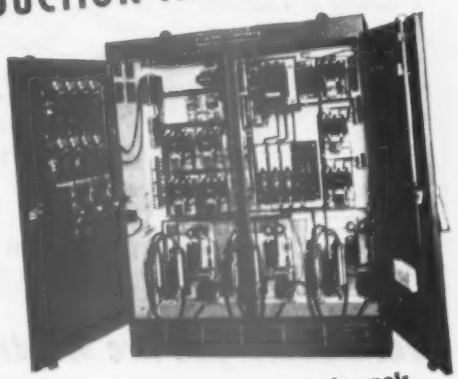
DESIGN LEADERSHIP

IN WELDER CONTROL FOR MASS PRODUCTION INDUSTRIES

A leading automobile manufacturer asked Square D to design magnetic and electronic control for a battery of 10 new multi-transformer welding presses. As many as 168 spot welds are made by one machine with 14 individually controlled timing periods in sequence.

Among the "must" requirements were:—welding current flow synchronized to prevent high starting transients and minimize stress on transformer windings; and a limitation of 1000 ampere current in each 3 phase line. *These 10 controllers are still providing trouble-free service after two years on the production line.*

Engineering counsel on any electrical control problem is available through Square D field offices in all principal cities.

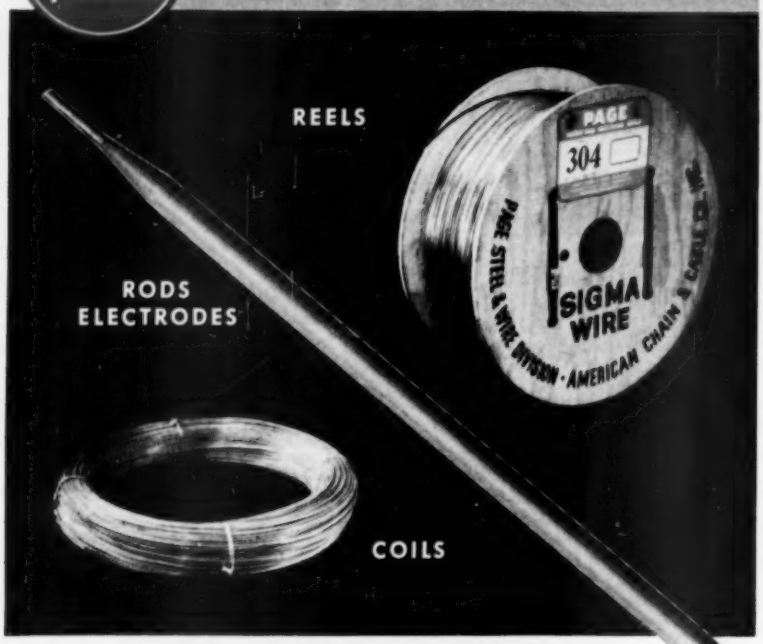


One of the completed control panels *Because Square D's line of control is so complete, this entire unit was designed using only standard devices, accessories and electronic sub-assemblies.*

SQUARE D COMPANY

1903 • 50 YEARS OF DESIGN LEADERSHIP • 1953

ACCO products for Stainless Steel WELDING



How Do You Buy It?

• No matter how you buy stainless steel welding wire—on reels, in coils, or packages of rods or electrodes—PAGE can supply you in a variety of analyses.

AC-DC Electrodes—Gas Welding Rods

Stable burning even at lower heats. Slag is clean and easily removed. Coating resists cracking right down to short stubs. Your choice from a complete line for every type of stainless welding.

for Inert Gas Welding

Six Page-Allegheny stainless grades in .035", .045", and .0625" diameters. Precision thread-wound on 25-lb. non-returnable reels to fit popular arc welding machines.

for Submerged Arc Welding

PAGE stainless in wire diameters from 1/32" to 5/16", plain or copper coated. In layer-wound coils, 22" or 24" mill coils, or 200-lb. returnable steel reels.

Write our Monessen, Pennsylvania office for literature and prices

ACCO

PAGE STEEL AND WIRE DIVISION
AMERICAN CHAIN & CABLE
Monessen, Pa., Atlanta, Chicago, Denver, Detroit, Los Angeles, New York, Philadelphia, Portland, San Francisco, Bridgeport, Conn.

PAGE Welding Electrodes Rods Wire

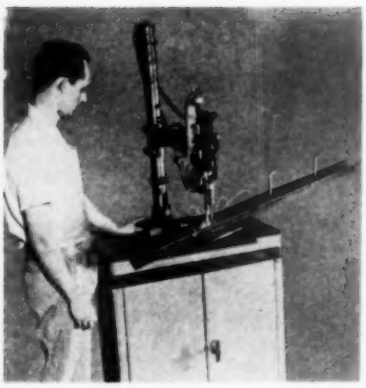


table-mounted production units designed for use in fabricating shops will install anchor studs at the rate of four to five per minute.

Nelson stud welding equipment, including battery and special motor-operated welding machines, is available on a rental or purchase basis through Nelson factory branch warehouses and dealers in all major industrial centers. Architectural details from which specifications for anchor studs can be obtained are available from company headquarters at Lorain, Ohio.

Stainless Steel Soldering Flux

Stainless Steel "48" is a soldering flux developed especially for use on stainless steel, Monel, Inconel, nichrome, chromium, manganese, molybdenum, tungsten and vanadium alloys. Low-thermal conductivity and a persistent oxide film usually cause difficulty in soldering stainless steel. This new flux removes oxides without affecting corrosion-resistant properties and assists solder to flow at the lowest possible temperatures. Stainless Steel "48" is suitable for solder iron, flame or dip soldering. Free sample for test use in your own plant may be secured from Remont Manufacturing Co., 1310 Myers Rd., Lombard, Ill. (For non-stainless-type metals, ask for sample of highly concentrated Tinstyter soldering flux.)

Resistance Welding Machine

A unique new welding machine, developed at Solar Aircraft Co. in San Diego, Calif., is slashing manufacturing and equipment costs through an innovation in resistance welding technique.

The Solar roll welder is used to automatically make circular seam welds on J47 jet engine exhaust cone assemblies. Designed and built at a cost of $14,000, the machine joins the afterburner fuel manifolds to the engine exhaust cone. One roll welder replaces seven spot welders—

The A. O. Smith *Champion* Heavy-Duty A. C. Welder

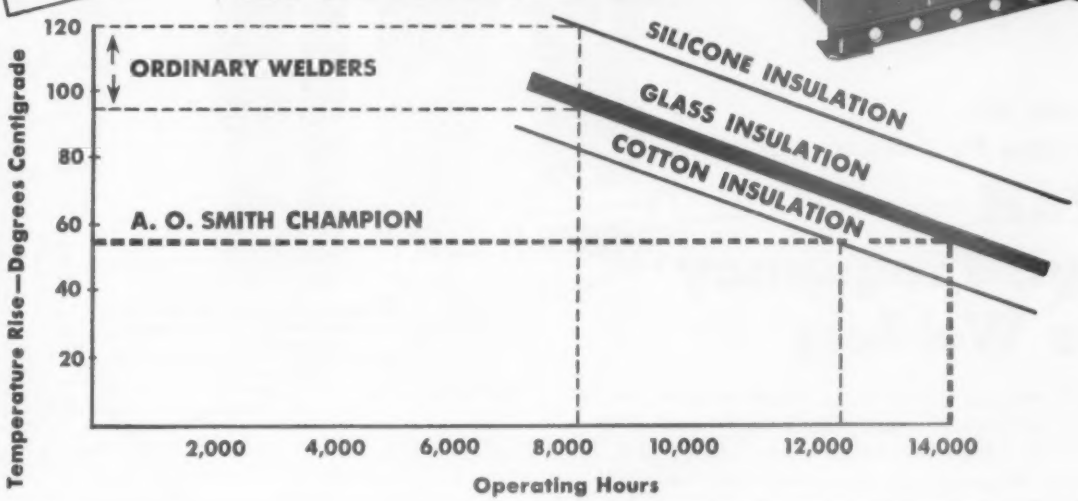
6000 hours longer life

than any other A. C. welder

Available in 300-, 400-, and 500-Amp. models.

PROOF

LIFE EXPECTANCY CHART



Temperature Rise Determines Machine Life

According to the Insulation and Aging versus Temperature Curves, as published by the A.I.E.E. . . . *the cooler a welding machine operates, the longer its production life.*

The A. O. Smith Champion is the *only* A. C. welder on the market with enough copper and cooling capacity to operate without exceeding a 55° C. temperature rise—as compared to the 90° C. rise allowed by N.E.M.A. for glass-insulated welders.

This means: The Champion will give you top production efficiency almost twice as long as any other A. C. welder on the market today.

Built for those who want the best in welding, the Champion has a full 75 open circuit volts, high-velocity down-draft ventilation, all-weather case, 12½ KVA power factor correction and stepless current control.

For additional information on welding machines, electrodes and accessories, see your local A. O. Smith distributor or write to A. O. Smith Corporation, Welding Products Division, Milwaukee 1, Wisconsin.

A.O.Smith
CORPORATION

WELDING PRODUCTS DIVISION
Dept. WJ-853, Milwaukee 1, Wisconsin
INTERNATIONAL DIVISION: MILWAUKEE 1
Made by welders . . . for welders

Only P&H DIAL-LECTRIC

INSTANTANEOUS REMOTE CONTROL lets you

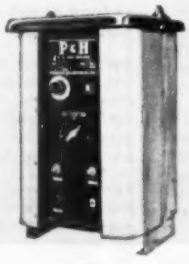
change heat lightning-fast

. . . gives you Inert-Gas Welding at its best, AC and DC

P&H AC Arc Welder

***You get this exclusive P&H feature in* P&H High-Frequency Arc Welders**

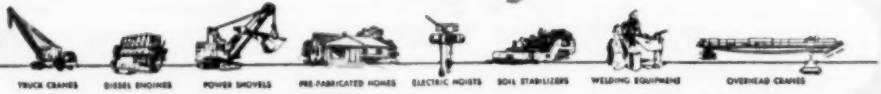
A simple turn of a dial or a touch of the toe gives you the heat you call for *right now* — not seconds from now! That's because P&H Dial-lectric Control is electrical, not mechanical. Response is instant — there's no time lag. It's a P&H "exclusive" that boosts production, cuts costs, saves time. And it's just one of the advantages you get with P&H High-Frequency AC and DC Arc Welders, available in sizes up to 625 amps. Ask your P&H representative or distributor for all the facts. Or write us for latest bulletins.



P&H DC Arc Welder

P&H WELDING DIVISION
HARNISCHFEGER CORPORATION
4551 W. National Ave. • Milwaukee 46, Wisconsin

the P&H *line*



2391

costing a total of $49,000—which were formerly required to do the same work.

With the special roll welder, cycle time for the welding operation has been cut almost 80%, from 4 hr to 45 min. One man operates the unit, where formerly seven operators were needed. Handling of the parts has also been significantly reduced.

In operation, the Solar roll welder makes a 3-in. diam seam weld around the support bosses of the fuel manifold. Usually in resistance welding the electrodes remain stationary while the part being welded is moved; in the Solar unit the seam-welder head, which is the moving member and constitutes the upper electrode, automatically rolls around a circular path while the work remains stationary.

Another unusual technical aspect of the welding machine is that the moving upper electrode carries approximately 14,000 amp through a $\frac{1}{2}$-in. diam shaft and a floating joint.

The lower electrode of the unit is essentially an air-operated clamping fixture. After positioning the work and closing the lower electrode, the welding operation is completely automatic. Welding speed is adjustable from 8 to 48 ipm.

Although the new Solar unit—known as the planetary geared roll welder—is a highly specialized machine, it is also extremely versatile. In less than 30 min the special tooling can be replaced by conventional tooling, making the machine a standard universal (circumferential or longitudinal) seam welder.

Versatility has also been stressed in the design of the special tooling. The size of the upper electrode's circular path may be varied from 0 to a 6 in. radius, making the machine adaptable to a wide range of circular welding operations.

Designed by Solar, the machine was built by Taylor-Winfield Corp. The basic unit is a medium series, 36-in. throat, 150-kva transformer, low inertia head seam-welding machine.

As a specialist in the fabrication of alloy steels for high temperature uses, Solar has developed many unusual welding methods and machines in addition to the planetary roll welder.

Spooled Wire for Automatic Inert Arc Welding

The Drawalloy Corp., wire mill producing stainless steel and tool steel wire for the welding industry, has commenced production of spooled wire for automatic inert arc welding in its new and enlarged plant on Lincoln Highway West at Alloy St., York, Pa., according to E. J. Brady, President.

Spooled wire of 0.035–$\frac{1}{32}$-in. diameters in all stainless steel grades is manufactured to the special chemical analyses required by the welding industry. The wire is precision-wound on labeled spools, easy for distributors and users to identify, stock and handle.

P&H

the industry's most complete line of cost-cutting welding equipment

P&H POSITIONERS

With one finger, you position heavy weldments for economical downhand welding. Capacities, 2500 to 36,000 lbs. — remote-control and hand-operated models.

P&H LOW-HYDROGEN ELECTRODES

13 types for high-strength welds on problem steels, steel castings, nickel-alloy steels, chrome-moly steels, .40 carbon castings, high-hardenable steels, aircraft and similar steels.

P&H AC WELDER

Exclusive P&H Dial-lectric Remote Control gives you instantaneous heat selection at the work. Sizes up to 625 amps., NEMA rated. Connectable to 220 and 440 volts.

P&H WELDING TWINS

P&H DC RECTIFIER WELDER

Also has P&H Dial-lectric Control, for fingertip heat control. Three sizes, 200, 300, and 500 amps., NEMA rated.

P&H WN-301 ENGINE-DRIVEN DC ARC WELDER

Portable—lets you weld anywhere, anytime. Has P&H Dial-lectric Control. Runs at only 1750 rpm. Welding service range, 60-375 amps., NEMA rated.

Ask your P&H representative or distributor for complete information, or write for free bulletins.

2591A

P&H WELDING DIVISION

HARNISCHFEGER CORPORATION

4551 West National Ave., Milwaukee 46, Wis.

Each spool contains about 25 lb of stainless steel wire, and consists of an extra-heavy expendable plywood spool packed in a new type of sturdy carton of Drawalloy Corp.'s own design.

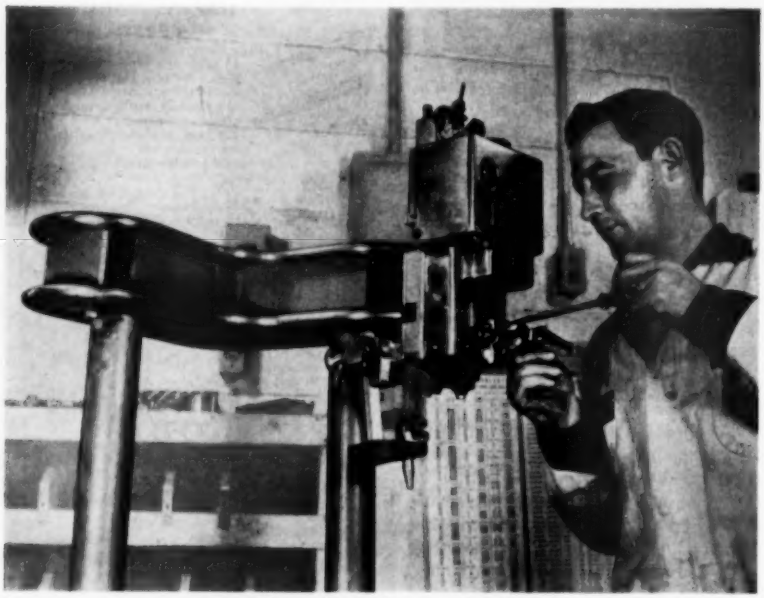
Complete information, prices and literature may be obtained by writing the Drawalloy Corp., York 16, Pa.

Three-Dimensional Cutting Equipment

The Milwaukee Shipbuilding Corp., 3718 W. Lancaster Ave., Milwaukee 9, Wis., has placed on the general market the first "three-dimensional" flame-cutting equipment for scarfing the edges of curved metal pieces in preparation for welded assembly of larger units.

Milwaukee Shipbuilding calls the flame-cutting equipment "three-dimensional" because it operates vertically, horizontally and at angles from the first two as it scarfs the edges of curved metal pieces. The third dimension is the operation of the cutting equipment around curves.

The new equipment centers on a flame cutter which moves under power as it follows the curves of the metal under process. The cutting flame slants at a constant angle from the desired apex of a scarfed edge. Devised was a system of twin rails whose rise, fall, tilts and turns match those of the metal under process. Four spring-loaded drive rollers and a spring-loaded idler roller keep the moving unit true to the path of the rails. The drive rollers move at speeds up to 15 ipm, powered by a $^1/_{25}$-hp electric motor. The speed range can be varied to suit customers' needs. One of the rollers in the drive group is serrated to prevent slippage when the unit enters a curve, where control must be absolute if deviations are to be avoided. The serrated roller cuts its own track in the guide rail which it follows.



Three Dimensional Cutting Equipment

The centers of the rollers are lined up with the desired position of the orifice when the equipment is built. The three rollers in effect are the moving unit's front wheels, whose "axle" is aimed at the apex point with the help of the tilt of the rails at curves. All the rollers except the serrated roller are concave to fit the rounded surfaces of the rails, which they grip from the sides under spring pressure.

The rails on which the unit rides are mounted on the fixture which holds the metal under process. Rails can be built in a complete circuit, if the job so requires, or in any portion of a circuit, guiding the unit up, down and around like a roller coaster. It has been found practical, however, to avoid cutting upward more than 22 deg if falling slag is to be kept away from the head.

Although the unit is being made in a standard size by Milwaukee Shipbuilding and the torch-cutting equipment obtained from well-known suppliers, each set of rails and the accompanying fixture must be built for the piece of metal being processed. The firm has made a unit big enough to hold a casting measuring 4 by 8 ft, permitting cuts of 16 linear feet along three sides at an angle of 22 deg off horizontal. Metal can be cut in thicknesses between $^1/_4$ and 8 in. at speeds up to 15 ipm. Speeds vary with the thickness of the metal to be cut.

Among features which add to the simplicity of operation of the "3-D" equipment are a quick reversal switch to carry the unit back to the starting point. Limit switches stop the cut at points where no cut is to be made or the angle is to be changed. A quick-acting double shutoff valve for oxygen and acetylene permits relighting without readjustment of preheat flames.

Among the new design possibilities made practical by the "3-D" equipment are the use of curving seams in curved metal which offer greater strength in welding than straight seams. Selection of the angles of scarfs in curved metal can be made with an eye to maximum strength not obtainable before.

WELDING CONNECTORS

Saxe Welding Connection Units position and secure structural parts to be welded.

Clip K3A permits an adjustable connection.

These widely used units eliminate all hole punching, and, with welding, produce the most economical, safe, and quickly erected structural frame.

Write for 1951 edition, Structural Welding Practice Manual.

J. H. WILLIAMS & CO.
Buffalo 7, N. Y.

AIR REDUCTION CANADA, LTD.
Montreal 2, Canada

Buy "PROVEN FLUXES"
Years of GUARANTEED SATISFACTION
behind these GOOD
"ANTI-BORAX" FLUXES

Insist on them — Unequalled Quality

No. 1 Cast Iron Welding Flux
No. 2 Brazing Flux for Brass, Bronze Steel, etc.
No. 4 Braz-Cast Flux for Bronze Welding Cast Iron
No. 5 & 8 Cast & Sheet Aluminum Fluxes
No. 9 Stainless Steel Welding Flux
No. 11 Tinning Compound
No. 16 Silver Solder Paste Flux

Mfg. By
ANTI-BORAX COMPOUND CO., INC.
Fort Wayne, Ind.

the unseen MR. "X"

WHO PUTS THE SOMETHING "XTRA" IN

BURDOX

WELDING AND CUTTING EQUIPMENT

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Provides every product...every process... to fit every purpose best

We call him Mr. "X"—not because he is an unknown quantity but rather because he represents an idea, a tradition, a way of doing business. Mr. "X" stands for the many highly trained welding experts who design and produce BURDOX products for every welding and cutting process—men whose vast experience and superior "know-how" adds that extra "something" to every BURDOX product. These men work toward the traditional BURDOX goal: *find a way to do it better, faster, cheaper, easier.* So regardless of what your needs are—welding and cutting equipment, industrial gases or safety equipment—there is a BURDOX product that can take the guess-work and delay out of solving your *particular problem.* Don't just buy welding equipment—buy BURDOX and save man-hours *and* money. *If you do not have the Burdett catalog be sure to write for your free copy now.*

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New copper solder type TWECOLUGS are especially designed for making cable connections; they have large diameter stud holes with ample wing nut clearance. 4 sizes for welding cables 6 through 4/0. 4 sizes for power cables 14 through 4.

TWECO "LUG-SET" SPLICERS

4 sizes for cables #6 through 4/0. Split rubber sleeves for good insulation with friction tape.

Use TWECO "Lug-Set" Splicers and rubber sleeves to splice broken or worn welding cable. Reel ends and short pieces can be quickly spliced into usable lengths.

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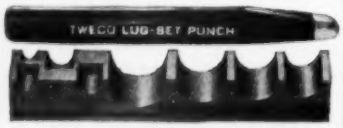

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Top and Bottom View of Lugs Attached

View of Splicer Attached with "Lug-Set"

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Resistance Welding Control

A new synchronous-precision control for fast high-quality resistance welding of hard-to-weld metals has been announced by the General Electric Co.'s Industry Control Department.

Adaptable for bench, spot, seam or combination welders, the simplified control is designed for reliability and long life, according to G-E engineers. It accurately regulates the value of the current and length of time it flows, to help assure high-quality welding especially where short durations of weld current are necessary for high-speed applications, they said.

The control was developed for use: (1) in welding stainless steel, aluminum, magnesium and other nonferrous alloys with a short plastic range; (2) where good welds with few rejects are necessary to keep production at peak capacity, such as in chain welding, relay components or electronic tube fabrication; and (3) where varying weld quality is not acceptable, such as in the manufacture of jet engines or airplanes. It can be used on motor-, fluid- or air-operated welding machines.

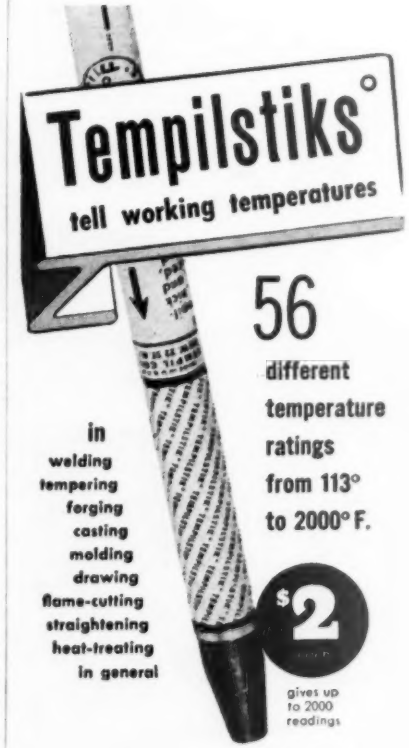
Basic components of the new synchronous-precision control are an ignitron contactor which acts as a switch to turn weld current on and off; a weld timer and phase-shift heat control; and a sequence timer, if required, which controls steps in the welding cycle, such as "squeeze," "hold" and "off."

The initiating circuit of the control can be either high or low voltage with one side of the circuit grounded for greater safety to the operator. A self compensating type of a-c circuit eliminates the need for voltage-regulating tubes, and because of the circuit design, G-E engineers said, the new panel is more stable on voltage variation and regulation, thereby giving increased reliability of operation.

They pointed out that the heat control and weld-timer panel is the same for all of the various types of synchronous-precision control (spot, pulsation, combination spot and pulsation, and seam-welding panels). Thus the equipment may be changed at any time from one type of welding control to another by adding appropriate plug-in assemblies.

Other features of General Electric's new control include surge resistors to increase firing-tube life, reduction of electrical losses through one-piece silver-plated copper bus bars, and positioning of the terminal boards at an angle on the side of the panel for easy access.

Ratings for the control are 180-280/410-510 v, 60 cycles. Dimensions for the 600-amp frame size are 54 by 20 by 11⅛ in. This model is adaptable for A-, B- and C-type ignitron tubes. The 1200-amp size measures 62 by 24 by 13⅛ in., and handles the B, C and D tube sizes.



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Rectifier Welder

Metal and Thermit Corp., New York, N. Y., announces the availability of a new DC Rectifier Welder in 200-, 300-, and 400-amp ratings. This machine is a heavy-duty unit built for day in and day

out service in production welding. Its design incorporates fan-forced, up-draft ventilation which provides unusually cool operating temperatures and assures long rectifier life.

For further information and prices write Metal and Thermit Corp., 100 E. 42nd St., New York 17, N.Y.

Aluminum Pipe Welding Machine

Air Reduction demonstrated an experimental model of a special aluminum pipe welding machine at the AMERICAN WELDING SOCIETY Exhibition, Houston, Tex., June 16–19, 1953.

Developed in cooperation with the Reynolds Metal Co. Engineering Department, this machine is designed for the field welding of aluminum gas gathering lines and oil transmission lines. The unit employs the Aircomatic Welding Process which, according to Airco, during the past few years has proved itself to be the fastest method of obtaining sound, dependable welds in aluminum. A consumable 43S aluminum wire is fed by guide rollers from a reel to the welding nozzle. At this point, the wire, weld and base metal are protected from oxidation by a shield of inert gas (argon, helium or a mixture of the two). A windshield around the nozzle insures complete gas shield for welding out of doors.

The welding machine is constructed of cast aluminum, weighs approximately 200 lb and measures 4 ft in diameter by $2\frac{1}{2}$ ft in width. A lifting eye is provided for raising and lowering the unit over the work. Once the machine is clamped to the pipe the welding gun circles it by means of a motor-driven worm gear. Adjustments are provided to accommodate 4-, 6- and 8-in. OD piping with wall thicknesses of $\frac{1}{8}$ to $\frac{1}{4}$ in.

One push button simultaneously starts shielding gas flow, wire feed, circumferential movement of machine and arc. At the completion of the weld the machine stops automatically. A weld on 6-in. OD aluminum piping is made in 17 sec.

Magnetic Clamps

Aronson Machine Co. of Arcade, N. Y., manufacturers of Aronson Positioners, proudly announce the new line of Magnetic Welding Clamps.

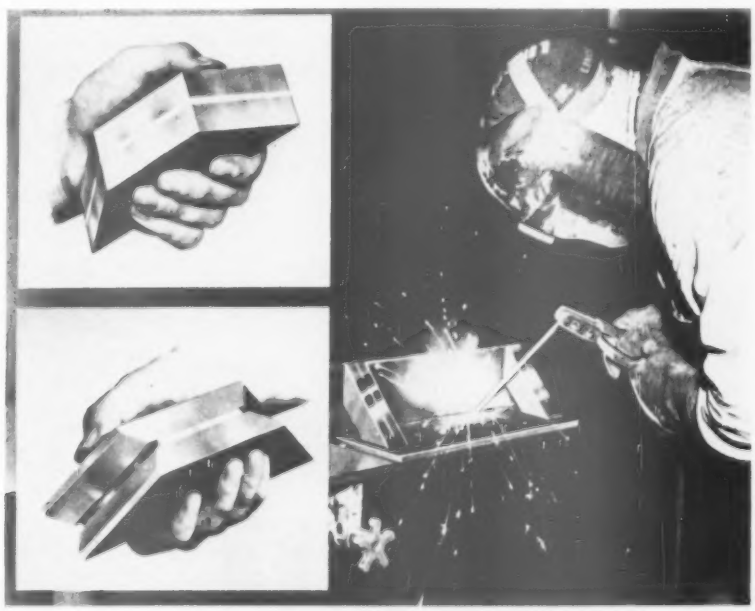
The clamps have many uses, but their most important function is in the welding field. They are used to locate and hold pieces of metal together for tacking and welding. Some jobs would be to hold two flats together for butt welds, or one piece 90 deg to another for fillets welds or two odd-size pieces for lap welds.

There are three models in the main line: The MCP or plain clamp with a 45 deg at either end and with a plain periphery. These are used to hold flats to flats. The Model MCV is vee'd at the ends but plain on top and bottom. They are used to hold rounds to rounds, rounds to flats or flats to flats. The MCA is adjustable to any angle. It consists of one set with two magnets attached with a link on either side held with a thumbscrew. They will hold light sheet metal at any angle for tacking and welding.

The Magnetic Cores are made of Alcomax, and since they are permanent, will be as good in 100 years as they were when purchased. There are no weight capacities for these clamps since this is not necessary information for the purpose for which they were designed.

Electrode for Inert-Gas Arc Welding

Costs of arc welding mild and stainless steel aluminum and magnesium are greatly reduced by using a new welding electrode, called Zirtung, which was exhibited by Sylvania Electric Products, Inc., at the Welding and Allied Industries Exposition held in June at the Shamrock Hotel, Houston, Texas. The improved performance of Zirtung results from the addition of a small amount of zirconium to the tungsten used in the welding electrode.



Magnetic Welding Clamps

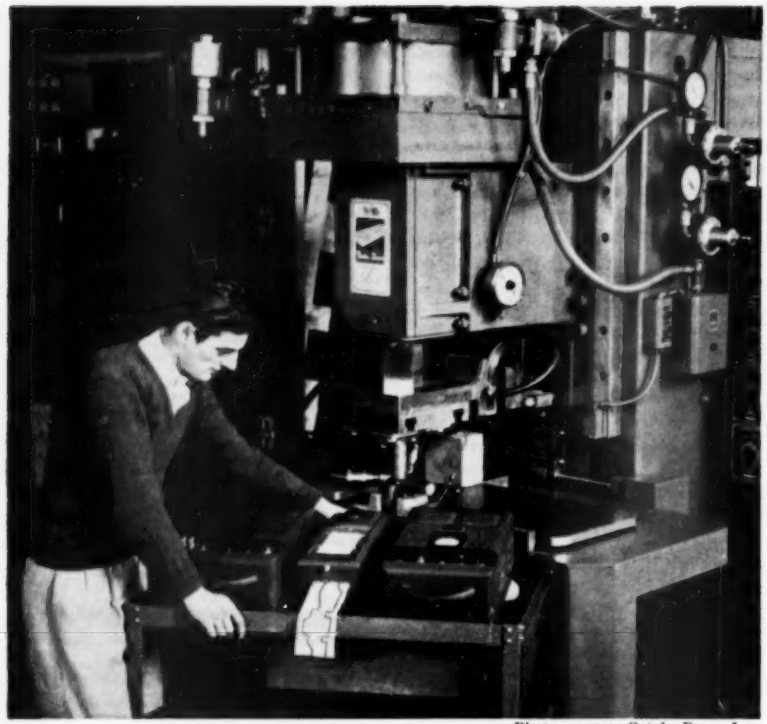


Photo courtesy Sciaky Bros., Inc.

Check calibration and performance with the BRUSH WELDING ANALYZER

Chart records of welding variables provide written proof of calibration and consistency of operation of welding equipment. Troubleshooting is speeded and specifications are met without trial and error.

The chart, recorded as the weld is made, shows the magnitude and timing of welding current and electrode force and indicates contact gage settings, precompression force, weld force, rate of rise, forge force and time of operation in milliseconds. You can visually and instantly spot faulty firing of power tubes or other difficulties.

For complete information on the Brush Welding Analyzer, write Brush Electronics Company, Dept. JJ-8, 3405 Perkins Ave., Cleveland 14, Ohio. Brush representatives are located throughout the U.S. In Canada: A. C. Wickman, Ltd., Toronto.

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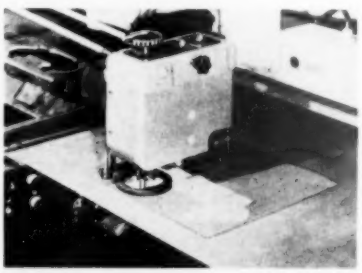
INDUSTRIAL AND RESEARCH INSTRUMENTS
PIEZO-ELECTRIC MATERIALS • ACOUSTIC DEVICES
MAGNETIC RECORDING EQUIPMENT
ULTRASONIC EQUIPMENT

The new welding electrode was developed by Sylvania especially for inert-gas arc welding. The presence of the small amount of zirconium in the tungsten effectively reduces the consumption of the electrode during welding. It also reduces the contamination of the electrode by the material being welded and has the advantage of being self cleaning without loss of electrode material. Zirtung is manufactured by Sylvania's Tungsten and Chemical Division at Towanda, Pa.

Precise Shape Cutting

A wide variety of metal shapes can be cut quickly and precisely with the Oxweld Automatic Tracer mounted on an oxy-acetylene shape-cutting machine. The new Tracer, introduced by Linde Air Products Co., a Division of Union Carbide and Carbon Corp., accurately reproduces the shape of any templet, even when the design is intricate or tricky.



Templets are easy to make. The desired shape is drawn to actual size on an inexpensive plastic sheet and cut out with scissors or knife. There is no need to allow for kerf when preparing the templet. Compensation for kerf width up to 1/4-in. wide is accomplished automatically by presetting a dial on the Tracer.

The tracing stylus always maintains positive contact with the templet to assure close tolerance. The Tracer can also be manually guided to follow directly a line sketch or blueprint.

SECTION NEWS AND EVENTS

as relayed to C. M. O'Leary

Annual Meeting

Boston, Mass.—One hundred and forty-nine members and guests of the *Boston* Section were present at the second annual social meeting, held on Monday, May 25th at the South Shore Country Club, Hingham, Mass.

Many took part in both the outdoor and indoor sports events during the afternoon. Prizes were awarded for various competitions as follows:

Golf—1st Gross, Tom O'Connor; 2nd Gross, Charles Donahue; 3rd Gross, Bill Toof; 1st Net, Bill Murphy; 2nd Net, Don Coulter; 3rd Net, Bob Bachman; High Gross, M. Metrick.

Horseshoe Pitching—Best team, Thure Johnson and Ralph Morin; most ringers, Thure Johnson.

Bowling—Warren Culbert.

At about 7:45, dinner was served, followed by an extremely interesting talk by Carl DeSuze, announcer and Master of Ceremonies of Radio and Television Station WBZ, Westinghouse, in Boston. After reminiscing, he showed a number of colored slides taken around the studio of thep ersonnel and equipment, and described some of the troubles of beginning telecasting before some of the present equipment had become available.

Newly Elected Officers

Bridgeport, Conn.—The *Bridgeport* Section announces the election of the following officers for 1953–54:

Chairman—James J. Powers, The Producto Machine Co., Bridgeport, Conn.
1st Vice-Chairman—William A. Seymour, Orange, Conn.
Secretary—Louis Campano, East Haven, Conn.
Treasurer—Romeo A. Lalli, R. A. Lalli Co., Bridgeport, Conn.
Chairman, Membership Committee—E. Staiano, Harris Sales & Service Co., New Haven, Conn.
Chairman, Program Committee—D. W. Chadwick, Washington, Conn.
Technical Representative—Joseph R. Skibo, Derby, Conn.

Election of Officers

Buffalo, N.Y.—The following officers and committee chairmen were elected by the *Niagara Frontier* Section for 1953–54.

Chairman—R. Thomas Breymeier, Union Carbide & Carbon Research Laboratories, Niagara Falls, N. Y.
1st Vice Chairman—F. Leo Rodgers, Jr., Kenmore, N. Y.
2nd Vice-Chairman—Donald D. Campbell, Snyder, N. Y.
Secretary-Treasurer—Robert Siemer, Buffalo, N. Y.
Chairman, Membership Committee—R. J. Saxton, Mills Welding Supply, Inc., Buffalo, N. Y.
Chairman, Program Committee—G. E. Claussen, Union Carbide & Carbon Research Laboratories, Niagara Falls, N.Y.
Technical Representative—M. W. Brewster, Snyder, N. Y.

Plant Visit

Cincinnati, Ohio.—Sixty-five members and guests of the *Cincinnati* Section obtained very valuable information from a tour of the plant of the Precision Welder and Flexopress Corp. on Tuesday, April 28th. This company has a national distribution of large line resistance-welding machines.

14th Annual Symposium

Cleveland, Ohio.—The *Cleveland* Section held its 14th Annual Welding Symposium on May 8th at the Allerton Hotel. This was one of the best the Section has held. The Symposium was an all-day affair with educational exhibits throughout the day, a technical session of three papers in the afternoon and a banquet in the evening. Following the practice of previous years, the Symposium was dedicated to an outstanding Cleveland individual who has contributed to the welding industry. This year it was dedicated to William Loveman, President of Burdett Oxygen Co. Mr. Loveman has been an active supporter of the AMERICAN WELDING SOCIETY and has been in the welding industry for 30 years. The dedication cited Loveman as "an outstanding example of the progress which can be achieved in our field . . a credit to our industry . . and because he has worked for and with his associates for so many years."

Approximately 30 different companies and organizations set up educational exhibits on the hotel mezzanine which formed the meeting place and social gathering during the day. They were well attended. A welder's bar was set up in conjunction with the exhibits after the technical session was over.

Under the Technical Session Chairman, N. C. Jessen, the afternoon meeting started at 2 P.M. with a paper by C. B. Voldrich, Battelle Memorial Institute, on "Inert Arc Welding of Titanium and Other Metals." He described the results of

Scene at Cleveland Symposium. (L. to R.) C. B. Grubbs, Burdett Oxygen; Herb Hinkel, G. E. Sales Engineer

recent study and research on this subject which judging from the turn-out for this first paper, is one of considerable interest to welding people in the Cleveland area.

The second paper on "High-Production Resistance Welding" was presented by Jack Ogden, Engineer in Charge of Welding Process Development at Fisher Body Division, General Motors. He described the use of multitransformer resistance-welding presses in high-production metal fabricating.

The last paper of the session was given by O. H. Kuhlke, Welding Engineer for General American Transportation Corp. His subject, "How and Where to Use Inert Arc Welding," covered the problems and their solutions which his work in fabrication aluminum tank cars has brought into his welding experience.

The technical session was attended by well over 175 persons.

The evening program was a dinner at which Mr. Loveman was honored as well as others who have been active in the Cleveland Section. Special recognition was given to Joe Wagner who has served as Secretary-Treasurer for the Section for many years. Mike Shane was toastmaster.

The featured speaker for the evening was Dean S. Newhouse, Dean of Students at Case Institute of Technology, who delivered an inspiring talk on "What Constitutes Leadership." Dean Newhouse held the large group of over 600 persons spellbound during his talk which left everyone inspired with the high principles of leadership that he outlined.

General Chairman for the meeting was J. Robert Henry, Welding Engineer, Cleveland Diesel. This closes the regular monthly meeting season.

Stag Party

Dallas, Tex.—An enjoyable evening consisting of a short meeting followed by a stag party was spent on May 28th by the members of the *Dallas* Section at the River Valley Country Club with an attendance of fifty.

Plant Tour

Dayton, Ohio.—The May meeting of the *Dayton* Section, held on the 12th, is one that will long be remembered by the 120 members, prospective members, and guests who made a tour of the plant of the International Harvester Corp. in Springfield.

It was a treat, not only to see the making of the truck bodies for panel and pick-up trucks, but also the assembly of parts such as axles, wheels, engines, etc., which go into the making of a complete truck. Of particular interest were the many types of welding that are involved in this assembly.

Annual Picnic

Dayton, Ohio.—The members of the *Dayton* Section—their wives as well as prospective members and their wives—all put aside their cares of the day and jumped in the family bus and drove to the Inland Manufacturing Activities Center, Miami River, Dayton, to attend the Annual Picnic held on June 9th and to participate in the activities which consisted of baseball, horseshoes, shuffleboard bingo, with the climax of the evening "Square Dancing."

Of course, a complete dinner, with all the trimmings, was served earlier in the evening and there was plenty of liquid to quench the thirst.

This year's picnic was again a big success, verified by the fact that there were approximately 100 in attendance.

Copper Clad Plates

Decatur, Ala.—R. C. Bertossa AWS of the Chicago Bridge and Iron Co., Birmingham, Ala., gave an excellent technical talk on the subject "Vacuum Brazing of Copper Clad Steel Plates" at the April 17th meeting of the *Huntsville-Decatur* Division of the Birmingham Section.

Common Sense in Welding

Decatur, Ala.—The last meeting of the current season of the newly organized *Huntsville-Decatur* Division of the Birmingham Section was held June 3rd at the "Why Not" Cafe. Thirty-four members and guests heard George Tepley AWS, Welding Specialist and Consulting Engineer from Chattanooga, Tenn., speak on the subject "Common Sense in Welding" and emphasize the necessity of "knowing your material, electrodes and procedure" for any successful welding job. Mr. Tepley also complimented the group for its successful organization as a Section Division.

A short business session was held after the speaker completed his excellent talk and great plans were made for the Division's Fall activities. Representatives from Birmingham were also present and announced the official recognition of the Division by the Birmingham Section.

The officers of the Huntsville-Decatur Division are: Forrest Holoway, *Chairman*; Robert B. Hunter, *Vice-Chairman*; Robert E. Conner, *Treasurer*; and Thomas H. Hughes, *Secretary*.

Welding vs. Castings

Denver, Colo.—A very interesting talk on "Welding vs. Castings" by a qualified speaker, Frank Latwig, of the C. W. Casey Welding Works, Colorado Springs, was presented at the June 9th meeting of the *Colorado* Section. Mr. Latwig spent most of his life with the St. Louis Steel Casting Co. until about two years ago when he moved to Colorado Springs and purchased the Casey Welding Works.

In lieu of a coffee talk, an entertaining film entitled "Behind the Scenes in Walt Disney's Studio" was shown.

Announcement was made of the result of the election as follows:

Chairman:—Herman Geller, Stearns Roger Mfg. Co.
1st Vice-Chairman—David C. Card
2nd Vice-Chairman—S. Rodda
Secretary-Treasurer—C. Brinton Swift, Linde Air Products Co.
Chairman, Membership Committee—H. B. Klodt
Chairman, Program Committee—W. D. Hooper, Linde Air Products Co.
Technical Representative—Robert B. Craig, Jr.

Those elected to the Executive Committee were Edward O. Browning, Maurice H. Eddy, J. L. Fry, H. Jackson, E. F. Jacobi, H. B. Klodt, V. A. Schroer and E. G. Watson.

Annual Meeting

Des Moines, Iowa.—The first annual business meeting of the *Iowa* Section was held on May 28th at the New Pastime Restaurant where a smörgåsbord style dinner was again enjoyed by the 29 members and guests present. Election of new officers for the coming year took place as follows:

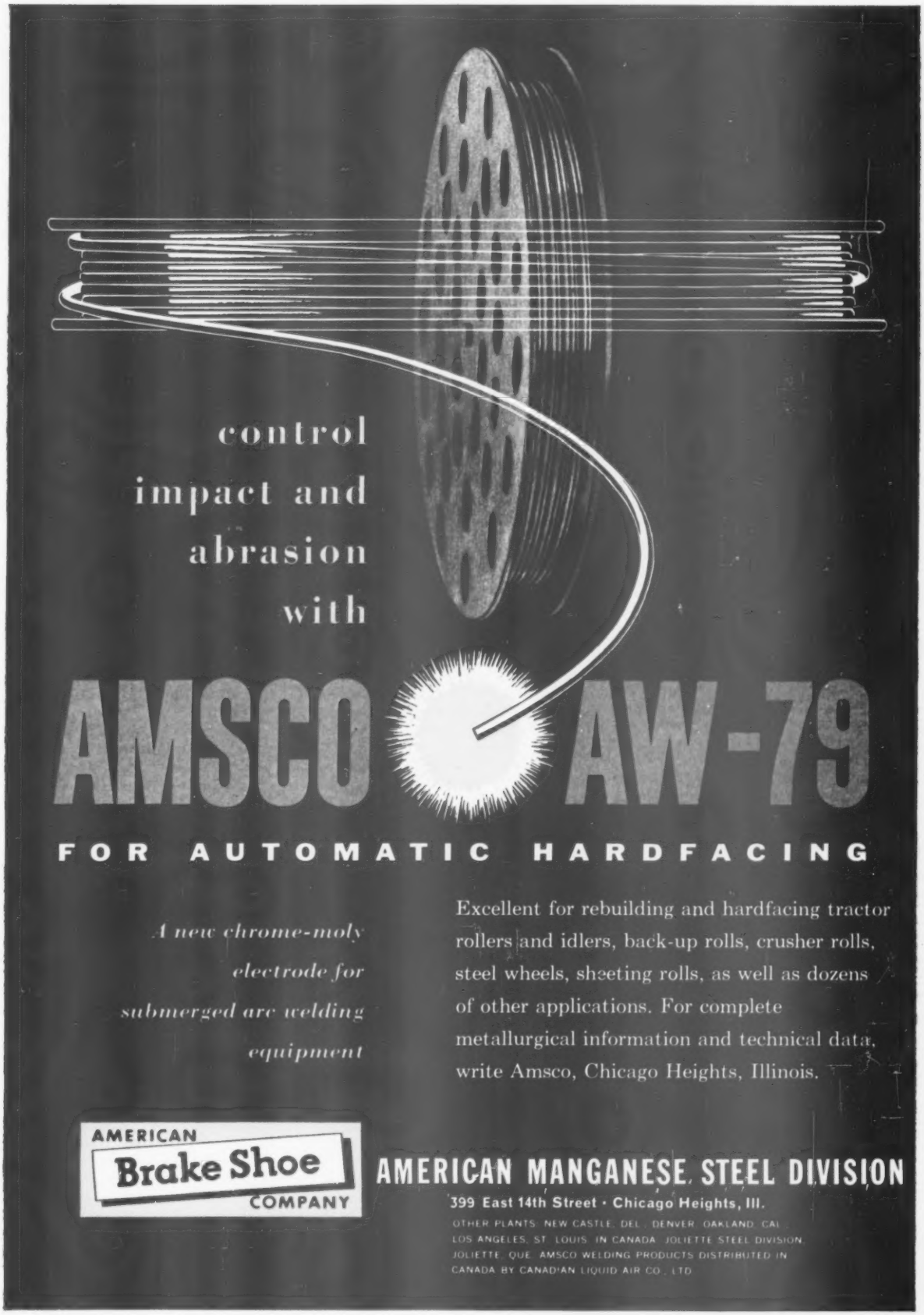
Chairman—James Wright King, Wright Welding Supply Inc.
1st Vice-Chairman—George C. Sullivan
2nd Vice-Chairman—Robert D. Warde
Secretary-Treasurer—David E. Shapter
Board Members—Edward A. Friedel, Russell Novy

A movie thriller "Kenya Safari" was shown after the regular meeting. The scenes flashed on the screen were those of an authentic hunting expedition in Africa headed by E. T. Meredith, Jr., of Meredith Publishers, Des Moines.

Annual June Social

Houston, Tex.—The annual June social and installation of officers and directors for the year 1953–54 was held by the *Houston* Section on June 29th at the American Legion Hall. One hundred and twelve members, guests and their ladies enjoyed a most delicious Bar-B-Que. The crowd was entertained by Miss Elaine Powell's lovely songs accompanied by Fred Courtney's accordion playing. Door prizes were awarded to several of the ladies and gentlemen.

The following officers and directors were installed for the coming year: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Chairman—W. H. Greer, Southwestern Laboratory
Vice-Chairman—James Earthman, Wyatt Metal & Boiler Works
Secretary-Treasurer—H. H. Wehner, Jr., Hughes Tool Co.
Directors (elected for two years)—Ben H. Allen, Mosher Steel Co.; Percy V. Pennybacker, Bridge Div., Texas State Hiway Dept.; Joe L. Lindinger, Engineers Testing Laboratories; Wm. S. Gleason, Linde Air Products Co.; Roy P. Pringle, Air Reduction Magnolia Co.; and Ernest O. Newman, Magnolia Welding Supply Co.
Directors (to serve one year)—Sam Hamilton, Chicago Bridge and Iron Co.; L. DeZavala, Dow Chemical Co.; G. C. Mathews, Wyatt Metal & Boiler Works; Tom Kegg, Jr., Champion Industrial Sales Co.; F. H. Berry, Big Three Welding & Equipment Co.; and Henry Howard, Wall Colmonoy Co.

Airlines Activities

Indianapolis, Ind.—Forty-three members and guests of the *Indiana* Section enjoyed the hospitality of the CAA on May 22nd at the Wier Cook Municipal Airport. Dinner was served airline style by stewardesses from the Lake Central Airlines.

Col. P. H. Rottger, Superintendent of Wier Cook Municipal Airport, gave a few introductory remarks and introduced Al Morris, Chief of the Technical Development and Evaluation Center of the CAA. Mr. Morris explained the functions of the center after which a motion picture showing some of their work with safety windshields and aircraft fire control was presented.

Welding Applications

Kansas City, Mo.—The *Kansas City* Section held its last scheduled meeting of the season on Thursday, May 14th, in Fred Harvey's Pine Room. A vote was taken and it was agreed to again meet in Fred Harvey's Pine Room for the coming season.

Newly elected officers for the coming season were announced as follows:

Chairman—A. J. Hedstrom, Kansas City Structural Steel Corp., Kansas City, Kan.
1st Vice-Chairman—G. G. Demecs, Westinghouse Electric Corp., Kansas City, Mo.
Secretary—D. E. Broderson, Butler Manufacturing Co., Kansas City, Mo.
Treasurer—M. J. Houghton, Koch Refrigerator Co., Kansas City, Mo.
Chairman, Membership Committee—N. C. Brink, Kansas City, Kan.
Chairman, Program Committee—F. G. Singleton, Kansas City, Mo.
Technical Representative—L. N. Williams, Kansas City, Mo.

Cares C. Keyser AWS, Welding Engineer, Bethlehem Steel Co., gave a nontechnical talk covering applications of different types of welding in the steel plant with special emphasis on the applications of the submerged arc process to maintenance work.

Aircraft and Rocketry Panel

Los Angeles, Calif.—At a dinner meeting of the Aircraft and Rocketry Welding Panel of the *Los Angeles* Section held on June 4th, the following panel officers were elected:

Chairman—Francis Stevenson
Vice-Chairman—Tom Bradley
Secretary—H. L. Meredith
Chairman, Program Committee—Dick Hayes

The subject of this panel, "Welding Today," was covered by Byron Russell, Owner, Airline Welding and Engineering Co., Inglewood, Calif.

Byron Russell is not only a very good autogenous expert, but he is also an excellent amateur photographer. He formerly was a Field Welding Engineer for the Linde Air Products Co. Having devoted 20 years of his time to the art and science of joining metals as a welding representative, he accumulated a great deal of information necessary for successful autogenous operations. With a huge backlog of experience and knowledge of up-to-date manual, semiautomatic and full automatic fusion-welding equipment, Mr. Russell finally resigned and went into business for himself. One of his main objectives as a job vendor was to become a proficient specialist in difficult-to-do weldments.

As is typical of perfectionists, Mr. Russell began recording his achievements by photographing all his work. At first, he used a still flash camera, but then later on, he acquired an 8-mm moving picture camera which he put to work with excellent results. The results of his recording endeavors are vividly shown in his movie, Welding Today.

It is easily seen, as the movie progressed, that a good deal of thought and ingenuity had been undertaken toward the development of versatile welding fixtures. As a specialist job-shop organizer, Mr. Russell pointed out that his objective is to be prepared for any job by having special portable tooling available that allows switch-over operations.

Mr. Russell showed a cantilevered pneumatic welding fixture that is capable of holding many different forms. This longitudinal welding jig is designed for continuous fusion seam welding either square butt or groove weld joints, and is capable of using automatic inert-gas-shielded nonconsumable or consumable electrode and submerged-arc processes.

Another of his illustrations showed one of his quick change-over welding setups; rigged to repair a huge casting by a constant potential submerged-arc welding process which he developed.

Election of Officers

Milton, Pa.—The *Susquehanna Valley* Section held an election of officers with the following results:

Chairman—Roy J. Holden, Jr., Milton, Pa.
1st Vice-Chairman—George L. Mieding, Kingston, Pa.
Secretary—Andrew J. Furman, Commercial Gas Corp., Wilkes-Barre, Pa.
Treasurer—Robert P. Schweyer, Berwick, Pa.
Chairman, Program Committee—Andrew C. Batten, Berwick, Pa.
Technical Representative—Lewis S. Russel, Berwick, Pa.

Newly Elected Officers

Minneapolis, Minn.—*Northwest* Section announces the election of the following officers for 1953–54:

Chairman—Arthur H. Hanson, St. Paul Structural Steel Co., St. Paul, Minn.
1st Vice-Chairman—W. E. Coleman, Linde Air Products Co., Minneapolis, Minn.
Secretary-Treasurer—Lillian K. Polzin, Minneapolis Chamber of Commerce
Chairman, Program Committee—W. E. Coleman, Minneapolis, Minn.

The Welding of Copper and Titanium

Oak Ridge, Tenn.—The *Northeast Tennessee* Section held a very successful dinner meeting on April 20th at the S & W Cafeteria in Knoxville. Coffee Speaker Bob Wilson, Sports Editor of the *Knoxville News Sentinel*, discussed the football outlook for the Southeastern Conference teams for the 1953 season. Eighty members and guests were present at dinner and 110 attended the meeting which followed.

Dr. John J. Chyle AWS, Director of Welding Research, A. O. Smith Corp., Milwaukee, spoke on "Welding of Copper and the Welding of Titanium." Of these two extremes in metallurgy, three grades of copper—tough pitch, deoxidized and OFHC—and several titanium alloys containing small amounts of Cr, Fe, Mn and Al were discussed. The titanium alloys weld very similar to pure titanium.

Copper is adaptable to welding by inert-gas W-arc, flash welding, spot welding and several other methods. In the inert-gas

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Northeast Tennessee Meeting. Bob Wilson, Coffee Speaker; J. R. McGuffey, Chairman; J. J. Chyle, Speaker

W-arc method helium gas is superior to argon for copper and titanium since no preheating is required with the helium. The use of direct current with a negatively charged regular tungsten electrode and with a backhand welding method, which gives a gradual solidification, is particularly useful in copper welding. Using these techniques, copper welds with tensile strengths of 30,000 psi and bend angles of 180 deg, properties equivalent to the unwelded material were obtained, except in the tough pitch copper welds.

Titanium can be welded by inert-gas W-arc, flash welding and spot welding. Titanium welds should be made with thinner layers per pass than copper welds. Using the inert-gas W-arc method, a thoriated tungsten electrode with direct current and a forehand welding method, which avoids hot short cracking with the thinner layers, gave satisfactory welds. The weld tensile strength was equivalent to stock metal, approximately 150,000 psi; however, low bend test results were obtained. By heat treating the weld zone, the bend test properties could be materially improved and this procedure is also useful in copper welds.

The talk was well illustrated with a number of slides to show the many interesting properties thus far found in the welding of copper and titanium.

Officers for 1953–54

Oak Ridge, Tenn.—The following officers and technical representative have been elected by the *Northeast Tennessee* Section:

Chairman—J. M. Case
1st Vice-Chairman—F. C. Miller
2nd Vice-Chairman—L. G. Domer
Secretary—D. G. Scott
Treasurer—G. M. Slaughter
Technical Representative—J. R. McGuffy

4th Annual Dinner Dance

Philadelphia, Pa.—The *Philadelphia* Section held its fourth annual dinner dance on May 16th at the Engineers Club, with an attendance of 200 members and guests. A most enjoyable cocktail hour preceded the affair. Program Chairman Fred Judelsohn did an outstanding job on the preparation and presentation of the party.

A most colorful decoration job was performed by Gus Garcia, who also rendered a number of fine vocal selections which rated loud and long applause.

Harry Pierce, President of New York Shipbuilding Corp., was guest of honor. He was introduced by retiring Chairman Rudi Guenzel who presented an inscribed certificate of merit for Mr. Pierce's outstanding contributions to the Philadelphia Section and the welding industry as a whole.

After a most delicious dinner, dancing was enjoyed until 1 : 00 A.M. with Joe Ferane's orchestra.

Plant Tour

Phoenix, Ariz.—The Consolidated Western Steel Division, U. S. Steel Corp., was host to the *Arizona* Section on Wednesday, June 17th. This company is acknowledged as the most progressive tank and pipe fabricating plant in Arizona and an extremely interesting tour was made through their plant. Of vital interest was the Federal flash welder with a 48-in. barrel.

Prior to the tour, a delicious buffet dinner was served.

Social Evening

Rochester, N. Y.—The *Rochester* Section held its last meeting before the summer recess at the Rochester Turners Club on May 18th. Immediately following a smörgåsboard dinner, a series of tumbling acts was presented by the Rochester Turners Club's youngsters.

Past-Chairman Gomer Stelljes was presented with a pin and the following officers were installed as follows:

Chairman—Clyde Martin, A. O. Smith Corp.
Vice-Chairman—Harvey Ainsworth, General Railway Signal Co.
Secretary—Walter Dick, Eastman Kodak Co.
Treasurer—Robert Cattanach, American Foundry & Machine Co.
Executive Committee—Richard Avery, Robert Barr, Nelson Martin, William Meyers, Ted Melatz, John McKenzie and Fred Hall.

Past-Chairman Stelljes congratulated the past officers for their fine support and wished the new officers success.

Election of Officers

San Francisco, Calif.—The *San Francisco* Section announces the election of the following officers:

Chairman—E. Paul De Garmo, University of California, Berkeley, Calif.
1st Vice-Chairman—Larry A. Kech, Basalt Rock Co., Napa, Calif.
2nd Vice-Chairman—Charles B. Robinson, Air Reduction Pacific Co., San Francisco, Calif.
Secretary—Lin Chamberlin, Aladdin Heating Corp., Oakland, Calif.
Treasurer—R. E. McCormick, Millbrae, Calif.

Resistance Welding

Sheffield, Ala.—The *Tri-Cities* Section held its first anniversary in the beautiful ballroom of the newly erected VFW building in Sheffield on May 28th. This gala affair started at 6 : 30 P.M. with a cocktail hour followed by a chicken dinner with all the trimmings. The dinner dance was attended by 175 members and guests including visitors from the Society Headquarters; also, executives of Huffman-Wolfe Southern Corp., Southern Constructors Co., Reynolds Parts Co., and Tennessee Valley Authority. Also represented was Linde Air Products Co. and many others. All committeemen of the Section were responsible for the grand success of this dinner dance.

After dinner, J. L. York, re-elected Section Chairman, introduced the newly elected officers as follows:

Vice-Chairman—R. Ahearn
Secretary—L. Garrett
Membership Committee—F. Wells and T. Green
Hospitality Committee—J. Rogers
Entertainment Committee—D. Smith, J. Patterson and E. Teague

E. Lindsey will remain Treasurer for another year. The new Executive Committee consists of J. York, *Chairman;* E. Pollard, R. Ahearn, S. Bishop, K. Brouten and L. Garrett.

F. J. Mooney, Assistant Secretary of the Society, gave a brief talk on the education offered members of the Society on welding and the allied processes. Mr. Mooney's talk was enjoyed by all and added much to the success of the meeting.

Officers and Guests of Tri-Cities Section (Left to Right): K. L. Broutin, E. A. Lindsay, F. A. Bodenheim, Jr, L. C. Garrett, Richard Ahearn, Jack York, Frank J. Mooney, Fred Wells, James H. Patterson and Jimmy Rodgers

F. A. Bodenheim, Jr., of the Federal Machine and Welder Co., Warren, Ohio, gave a very fine talk on resistance welding and showed a sound movie on the welding of household utensils, which was of great interest to the ladies present. The Tri-Cities Section has rated Mr. Bodenheim as one of the best speakers of the year and they extend their appreciation to the Federal Machine and Welder Co.

The meeting closed at 9:00 P.M. George Stanford and his orchestra furnished dance music until 12:00. Every one attending this gala affair are still talking about the wonderful time they had.

The Tri-Cities Section has gradually grown throughout the past year and has had marvelous speakers at all their meetings.

Toledo Section Officers

Toledo, Ohio.—The following officers and Chairmen of Committees have been elected by the *Toledo* Section:

Chairman—William E. Morris, Welders Needs, Inc.
1st Vice-Chairman—Harry W. Hansen, Hans Hansen Welding Co., Inc.
2nd Vice-Chairman—Rolland E. Stentz, Holland, Ohio
Secretary-Treasurer—Harley W. Weide, Welders Needs, Inc.
Assistant Secretary—John Wolcott, Lincoln Electric Co.
Chairman, Membership Committee—Rolland E. Stentz
Chairman, Program Committee—Harry W. Hansen
Technical Representative—John DeWitt

Election of Officers

Tulas, Okla.—The *Tulsa* Section announces the election of the following officers:

Chairman—Morris White, National Tank Co.
1st Vice-Chairman—R. H. Wainright
2nd Vice-Chairman—Phil Koons
Secretary—L. F. Douglas, General Electric Welding Div.
Treasurer—Henry Ping, Jimmie Jones Co.
Chairman, Membership Committee—Vern Hartley, General Electric Welding Division
Chairman, Program Committee—W. H. Jaggers
Technical Representative—F. L. Silvers

abstracts of CURRENT WELDING PATENTS

Prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington, D. C.

2,639,634 and 2,639,633—Cold Welding of Metal—Anthony Bagnold Sowter, Wembley, England, assignor to The General Electric Co., Ltd., London, England.

These patents relating to the cold welding of metal cover apparatus especially adapted for cold welding outwardly extending flanges of a preformed circular-bent metal strip. The apparatus is adapted to apply welding pressure to the outside surfaces of the outwardly extending flanges and the apparatus includes cooperating outwardly extending peripheral shearing edges positioned at the side of the pressure-applying means to shear off the outer edge portions of the flanges simultaneously with the welding of the flanges together. More specifically, the apparatus includes a hammer mounted for movement to and from engagement with a die and energy storage or release means associated with the hammer for causing it to impart an impacting welding pressure upon the die and any metal positioned thereover.

2,640,133—Apparatus for Electric Arc Stud Welding—Arthur Ratcliffe Ainsworth and James Binnie Miller, London, England, assignors to Cyc-Arc Ltd., London, England, a British company.

The patented stud welding apparatus comprises a body, and a stud chuck carrier axially movable in the body and consisting of two co-axial relatively movable parts.

Clutch means are provided within the body for engaging the inner part of the stud chuck carrier to immobilize it, while electromagnetic means are present for attracting the outer part into contact with the inner part.

2,640,134—Hydraulic Flash Welder Control—Kingsley A. Doutt, Detroit, Mich.

The control apparatus disclosed in this patent relates to a flash welder having a normally fixed platen and a movable platen operated by a fluid pressure motor. The control apparatus includes a valve for controlling a secondary-fluid-pressure-operated motor in such a manner that the movable platen, in its movement, has a predetermined position-speed relationship during the flashing period of the welding cycle.

2,640,135—Electrode—James D. Cobine, Schenectady, N. Y., assignor to General Electric Co., a corporation of New York.

Cobine's patent relates to a sintered nonconsumable electrode capable of starting an arc instantly and maintaining a stable arc. The electrode comprises 100 parts by weight of tungsten and 5 to 45 parts by weight of thoria.

2,640,136—Electrode for Underwater Cutting—Bela Ronay, Annapolis, Md.

In this patent, the special electrode comprises an elongated main body of siliconized silicon carbide, and a metallic sheath surrounding the main body of the electrode and closely interfitting therewith. The sheath extends longitudinally of the electrode body to provide a low resistance path for current flow from a remote point of attachment to a working end of the electrode.

2,640,180—Welding Apparatus—John R. Parsons, Kenmore, N.Y., assignor to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

This patent relates to specialized apparatus for a timing system for timing transfer of current from a three-phase source to a single-phase load. The specialized apparatus includes various arc discharge devices connected in current controlling relation between one phase of the three-phase current source and the load, and includes other specialized connecting means for effecting the desired transfer.

2,640,960—Welding Transformer—Earl Force, Newton Falls, Ohio, assignor of 50% to Webster B. Harpman, Poland, Ohio.

Force's patent is on a welding transformer for transforming three-phase alternating current into single-phase alternating current of the same frequency. The transformer comprises three apertured cores positioned in special relationship to each other.

2,641,673—Welding Apparatus—Robert E. Dahl, Hinsdale, Ill., assignor of one-half to Advance Transformer Co., Chicago, Ill., a corporation of Illinois.

This patent relates to welding apparatus including a mandrel and means for setting the edge of a sheet metal member on a given line of the mandrel. The patent covers details of such gaging means.

2,641,674—Method of Joining Thin Metallic Sheets—Howard S. Orr and Alfred Teplitz, Pittsburgh, Pa., assignors to United States Steel Corp., a corporation of New Jersey.

This patented method of joining thin metallic pieces comprises attaching a thin piece of metal whose conductivity is higher than that of the metal pieces to one of the pieces adjacent an edge thereof. An edge of the other piece is lapped over this edge of the first piece and over the piece of metal attached thereto, and an electrical resistance weld is applied to the lapped edges of the pieces through the additional thin piece of metal positioned intermediate the overlapped metal pieces or sheets.

2,642,515—Remote Control for Arc Welding—Earle W. Bagg, Sans Souci, Mich.

Bagg's control relates to an arc-welding generator remote to the actual welding operation. The generator has a reversible electric motor-driven rheostat regulating its field current, and a welding and a control relay system is located at the generator. A welding current lead extends from the generator to the welding electrode and a welding current ground lead extends from the generator to the work. The welding relay system is normally open and closable responsive to striking the arc, and the control relay system includes two relays each closable responsive to the application thereto of a different definite current value lower than the welding current value closing a circuit from the generator to the motor-driven rheostat. One, relay and circuit drive the motor in one direction and turn the rheostat to increase the welding current, and the other relay and circuit drive the motor in the other direction and turn the rheostat to decrease the welding current. Two, resistances of different capacities are provided for connection to the welding current lead at the site of the welding operation to selectively introduce either different resistance into the control relay system and actuate one or the other of the relays in such system.

2,642,516—Binder for Filler Materials in Tubular Welding Rods—Howard S. Avery, Mahwah, N. J., assignor to American Brake Shoe Co., New York, N. Y., a corporation of Delaware.

The novel binder disclosed in and covered by this patent relates to an inorganic chemical compound selected from the sodium metasilicate hydrates and it provides a binder for the filler materials in the welding rod.

2,642,517—Method of Protecting Butt-Flash Welded Articles from Weld Splatter—Arthur L. Lindow, Macedonia, Ohio, assignor to The Cleveland Pneumatic Tool Co., Cleveland, Ohio, a corporation of Ohio.

This patent relates to the butt flash welding of two tubular members and includes the step of protecting the inner walls of the members from weld splatter by inserting into each member adjacent the end intended to be welded a combustible tubular shield of sufficient thickness to assure rigidity. Oxidation from the welding heat of such tubular shield is prevented by removing the oxygen from the shield, and subsequent to the welding operation, the shields are burned off to remove them and the loose splatter from the interior of the welded members.

2,642,560—Rotatable Welding Ground Clamp—John L. Elkins, Long Beach, Calif.

This patent is on a special type of an electrical grounding device.

2,642,652—Method of Making a Welded T-Joint—Raymond C. Davis, Dayton, Ohio, assignor to General Motors Corp., Detroit, Mich., a corporation of Delaware.

This patent relates to process of welding two solid metal rods wherein a notch is joined in only one-half of a cross section of one of the rods and the displaced metal from the notch flows outwardly for forming a laterally extending integral lip projection on such rod. The end portion of the second rod is inserted into assembled relation with the notch in contact with and overlying the laterally extending lip projection. The rods are then electrically welded at the notched portion and simultaneously the assembled portion of the rods is caused to be deformed for integrating the laterally extending portion with the metal of the end portion and to form a substantially flush, strong joint between the rods.

2,642,656—Method of Welding or Cutting Metal and Other Materials by Chlorine Fluoride Torch—Aristid V. Grosse, Haverford, Pa., assignor of one-half to Jacque C. Morrell, Merion, Pa.

This new cutting or welding method includes heating the material to be cut or welded by the combustion of a fuel from the group comprising hydrogen and hydrocarbon gases in the presence of a supporter of combustion. This combustion supporter comprises chlorine fluoride in sufficient amount to increase the temperature of the flame.

2,642,965—Weldment and Process for Making High-Tensile Steel Weldments by Electric Arc Welding—François Georges Danhier, Anderlecht, Belgium, assignor to La Soudure Electrique Autogene Societe Anonyme, Brussels, Belgium.

This patent is on a weldment of low-alloy, high-tensile steel having composite steel pieces each of which has a backing of low-alloy, high-tensile steel which has a cladding layer of low-carbon, plain-carbon steel. A plurality of electric arc weld beads join the pieces together and comprise weld-annealed beads joining the low-alloy high-tensile steel and an outer as-welded bead joining the low-carbon, plain-carbon steel layers only.

2,643,318—Weld Wheel Construction for Seam Welders—Arthur L. Williams and Emmet A. Craig, Warren, Ohio, assignors to Federal Machine and Welder Co., Warren, Ohio, a corporation of Ohio.

The patented weld wheel has a special annular chamber provided therein for receiving coolant means. Other sealing means are provided in association with the coolant receiving annular chamber.

2,643,319—Method of Electric Arc Welding—Paul Christiaan van der Willigen, Eidhoven, Netherlands, assig[illegible] to Hartford National Bank and Tr[illegible] Hartford, Conn., as trustee.

In [illegible]od, two metallic work[illegible]d each other and [illegible] between the workpie[illegible] electric current is passed through the metallic workpieces to initiate a welding arc therebetween and the electric current is continued until the slag-forming body begins to melt and deform to permit the metallic workpieces to approach each other. A welding contact between the workpieces is permitted after a predetermined period of time subsequent to initiation of the welding arc.

LIST OF NEW MEMBERS

Effective June 1, 1953

Membership Classification

A—Sustaining Member
B—Member
C—Associate Member
D—Student Member
E—Honorary Member
F—Life Member

ANTHONY WAYNE

Day, Cyril L. (B)

ARIZONA

Gibbons, John J. (C)

BOSTON

Blink, Leo G. (C)
D'Entremont, Victor P. D. (C)
Grant, George R. (C)
Terry, William J. (C)

CHATTANOOGA

Marshall, William (C)

CHICAGO

McCracken, James E. (B)
McCrink, Edward J. (B)
Morrison, W. L. (B)
Skubik, Emil B. (C)
Svenson, Ernest J. (B)
Weber, Harry C. (B)

CLEVELAND

Drown, Dano S. (C)
Eguchi, Mitsuo (B)
Humberstone, K. J. (C)
Lynch, John J. (C)
Menefee, Ray H. (B)
Ripich, John J. (C)
Spinks, Robert G. (C)

COLORADO

Fischer, Paul (B)
Smith, William S. (B)

COLUMBUS

Annie, Tony (B)
Churchheus, C. W. (C)

DALLAS

Anderson, Axel W. (C)
Carpenter, Earl C. (C)
Jones, J. A. (C)

DAYTON

Hall, Thomas M. (B)

DETROIT

Alyea, H. B. (B)
Butcher, Wilson C. (B)
Dunlap, David B. (B)
Goyeau, Earl (B)
Hartwick, Henry W. (B)
Milton, Bond (B)
Pfeiffer, Herman J., Jr. (B)
Powers, Roy (C)
Traum, John P. (B)
Wooll, Alfred C. (B)

HOUSTON

Butler, George D. (C)
Martin, Ken D. (B)
Waldrop, Roy (B)
Wall, T. B., Jr. (B)

INDIANA

Halcomb, Herman, Sr. (C)

IOWA-ILLINOIS

Bogott, Norman (B)
Rexroth, Harold E. (C)

LONG BEACH

Apsley, Lester T. (C)
Buster, Vernon R. (B)
Gentry, H. R. (C)
Hughes, Robert B. (C)
Larson, Eric V. (C)
McCarty, Daniel Groce (C)
Nordgren, Carl O. (C)
Stone, H. J. (C)

LOS ANGELES

Bailik, W. (B)
Brady, Elliot W. (B)
Brouillette, Lee (B)
Meyer, R. B. (B)
Swan, Harlan R. (B)
Sweeney, George W. (C)
Torrance, William (B)

MARYLAND

Lemmon, Joseph M. (C)

MICHIANA

Schroter, Richard C. (C)

MILWAUKEE

Koch, Richard H. (B)
Small, A. L. (C)

NEW JERSEY

Browning, George C. (B)
Flatland, R. D. (B)
Lawrence, Arthur (C)

NEW ORLEANS

Boudousquie, Angelo A., Jr. (B)
Smith, Bernard N. (B)

NEW YORK

Leiman, Jay (C)
Panish, Alexey J. (B)
Thoren, Anders V. (B)

NIAGARA FRONTIER

Burch, William L. (B)
Evans, Harry B. (B)
Gill, E. A. (C)

NORTHERN NEW YORK

Norton, Neil (C)
Porter, Ellis Owen (C)

NORTHWEST

Morin, William T. (C)

OLEAN-BRADFORD

Ley, Regis F. (C)

PHILADELPHIA

Bryand, Edward Thomas (C)
Galletley, George W., Jr. (C)
Johnson, Wayne E. (B)
Pippart, Karl A. (C)

PITTSBURGH

Heller, Philip N. (C)
Seader, John E. (B)

PUGET SOUND

Ebaugh, John (B)
Stern, Marvin J. (C)

RICHMOND

Haile, E. C. (C)
Hammond, Robert (C)
Ridgeway, William (B)

ROCHESTER

Raut, Harold D. (B)

SAGINAW VALLEY

Blackhurst, Glenn E. (B)
Cady, David (C)
Carter, Richard W. (C)
Cron, William (B)
Cunningham, William C. (C)
Lyngar, Charles Dale (D)
Miller, Bruce (C)
Rehkugler, Gerhard (D)
Rowe, Gaylord H. (C)
Schmidt, Ted C. (C)

ST. LOUIS

Allina, Stanley F. (C)
Franklin, Robert Hayes (C)

SALT LAKE CITY

Webb, Phillip H. (B)

SAN FRANCISCO

Glenn, George G. (B)
Keen, Robert David (B)
O'Brien, Clifford G. (B)

SANGAMON VALLEY

Beeker, H. G. (C)
Floreth, Earl Henry (B)
Harvey, Edward L. (C)
Hodges, Bob (C)
Peek, Robert C. (B)
Sauner, Bernard E. (C)

SUSQUEHANNA VALLEY

Meldrum, Robert A. (C)

TOLEDO

Baughman, Merle J. (C)
Edwardson, C. E. (C)
Gunlite, Richard W. (C)
Tafelski, Peter H. (C)

TRI-CITIES

Rowe, James O. (B)

WESTERN MASSACHUSETTS

Palmer, Arland F. (C)

YORK-CENTRAL PENNSYLVANIA

Rill, Elmer K. (B)

NOT IN SECTIONS

Hall, T. C. (C)
Hufham, Wbis, Jr. (B)
Redden, Thomas K. (B)
Redingef, Earl (B)
Wardstrom, Ben (C)
Weaver, Brian Raymond (B)

Members Reclassified

During the month of June

LOS ANGELES

Stewart, Russel (C to B)
Toland, John A. (C to B)

NOT IN SECTIONS

Bradley Frank W., Jr. (D to C)

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WELDING RESEARCH COUNCIL

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Supplement to the Welding Journal, August, 1953

Effects of Electrodes and Heat Treatments on Mild Steel Weldments

The beneficial effects of low-hydrogen type electrodes, preheat, postheat, and stress-relief heat treatments on the ductility and transition temperature of mild steel weldments

by Ernest F. Nippes and Alexander Lesnewich

Abstract

The ductility of weldments made with E6010 and E6016 electrodes on three plain-carbon silicon-killed 1-in. steels was studied with the Kinzel test. In the as-welded condition, the E6016 electrode was superior to the E6010 electrode only with the steel containing 0.25% carbon, the highest of the three carbon contents investigated. For all other conditions of preheat and postheat investigated in these three steels, there was no difference in the transition temperature between E6010 and E6016 electrodes. Although some improvement of the transition temperature of welded specimens was found with a 400° F preheat or a 24-hr postheat at 400° F, a combination of these two treatments was shown to be more effective. The most effective of the methods investigated for restoring the ductility of weldments was a 1-hr stress-relief heat treatment at 1150° F. In summary, low-hydrogen electrodes, even with 400° F preheat and/or 400° F postheat, did not produce weldments in plain carbon steels which were as notch tough as thermally stress-relieved weldments made with cellulose-type electrodes.

A preliminary study of the effects of the thermal cycles of welding on the ductility of three plain carbon steels was undertaken. Using a high-speed time-temperature control device, Schnadt-type samples were heat treated to duplicate the heating and cooling cycles experienced at four positions near an actual weld. The results of slow-bend tests of the Schnadt-type samples with three conditions of stress concentration were presented and discussed. For the plain carbon steels, the regions outside the normally considered heat-affected zone were shown to have poorest ductility, while the fine-grained regions were shown to have the best ductilities of the regions studied.

Ernest F. Nippes and **Alexander Lesnewich** are connected with the Welding Laboratory of the Department of Metallurgy of the Rensselaer Polytechnic Institute, Troy, N. Y.

Presented at the Thirty-Third National Fall Meeting, AWS, week of Oct. 19, 1952, Philadelphia, Pa.

INTRODUCTION

ALL structural steels show an appreciable plastic deformation before failure under usual service conditions. However, under some conditions of service the same steels will fail without deforming or giving any other signs of impending failure. Kinzel has compared these failures to those of tin cans and glass jars after storage for long periods of time with an increasing build-up of pressure due to the decomposition of their contents. The metal can will bulge as the pressure increases and may produce a small tear to permit the gases to escape and relieve the pressure. The glass jar, however, will fail suddenly when the internal pressure produces a stress state above the fracture stress of the glass. This sudden, unexpected type of failure in a structure may be very violent and can very easily cause its complete destruction.

In a steel the prime factors which affect these conditions of brittle failure are the strain rate, stress distribution and temperature. Hollomon and Zener[1, 2] have

developed a mathematical relationship between these factors which shows that for a given steel in a given condition of heat treatment the temperature of embrittlement is a function of the sample and notch geometry, and the rate of loading. With all conditions held constant, the temperature at which transition from ductile to brittle failure occurs can be used to compare the susceptibilities of steels in various conditions of heat treatment to embrittlement.

In addition to the mechanical features of testing, the temperature at which a steel ceases to behave as a ductile material has been shown to be a function of its composition, mechanical deformation, residual stress state, heat treatment, grain size, deoxidation and rolling practice, and the existence of other metallurgical phenomena such as strain and quench aging. Because of these effects, it becomes obvious that welding, with its associated metallurgical changes and increased residual stress state, will have a considerable effect upon the embrittling temperature of a given steel. It has been shown by others[3–8] that welding will raise the transition temperature, i.e., embrittle the steel. It is not unreasonable to expect that this temperature is affected by the type of welding electrode, weld energy input and preheat and postheat treatments which are used to produce the weldment.

SCOPE

The primary aim of this investigation was the determination of the beneficial effects of preheat, postheat and stress-relief heat treatments on the ductility and transition temperature of weldments. Another objective was the comparison of the effect on the ductility of welded joints when using low-hydrogen type electrodes as compared with cellulose-coated electrodes, with and without the thermal treatments mentioned above. In particular, it was the purpose of this research to investigate:

1. Whether low-hydrogen electrodes, without preheat, would produce weldments in plain carbon steels which would be nearly as notch tough as thermally stress-relieved weldments made with cellulose-type electrodes.

2. Whether low-hydrogen electrodes, with 400° F preheat, would produce weldments in plain carbon steels equal or superior to the thermally stress-relieved weldments made with cellulose-type electrodes.

This report has been divided in two sections, as follows:

Part I. The Effects of Welding Techniques and Electrodes. This portion of the investigation utilized the Kinzel test[5] to determine the effects of the type of electrode coating, weld energy input, preheat, postheat and stress-relief heat treatments on the ductility of weldments made in three plain-carbon silicon-killed steels.

Part II. The Effect of Thermal Cycles of Welding. This portion of the investigation utilized a Schnadt-type sample[25, 26] to determine the effects of weld thermal cycles on the ductility of three plain-carbon silicon-killed steels. These samples were synthetically heat treated by means of a high-speed time-temperature controller which duplicated the thermal cycles present in heat-affected zones.[17]

Part I. The Effects of Welding Techniques and Electrodes

INTRODUCTION

The initial portion of this investigation was undertaken to determine the effects of the hydrogen content of the electrode coating, weld energy input, preheat and postheat treatment, and type of steel upon the ductility of a weldment. The Kinzel notched slow-bend test was used for this investigation since the works of Kinzel[5] and Rieppel and his associates[7] indicated that this test would best reveal the embrittling effects of welding and its associated heat treatments. By using this test, the base plate, weld metal and heat-affected regions will contribute to the character of the ultimate failure of the sample. A region of extreme embrittlement may initiate a brittle fracture which, by the formation of a condition of extreme stress concentration and by an increased strain rate, could be rapidly propagated through a normally ductile structure. As a result of this situation, a small amount of brittle material in a sample can produce a radical change in the behavior of a normally ductile specimen.

Preparation of Samples

The Kinzel-test samples used in this part of the investigation were 8 in. long, 3 in. wide and 1 in. thick. Rough blanks were flame cut from the as-received 1-in. plate with the longitudinal axis parallel to the rolling direction. A water-cooled abrasive cut-off machine was used to finish these blanks to their final dimensions. Sufficient metal was removed from the sides to eliminate completely any steel which had been affected by the heat of flame cutting. Since the ends of the specimens would not affect the condition of the metal in the vicinity of the centrally located notch, a flame-cut surface would be permissible here. However, for accurate positioning in the testing jig, it was necessary to machine one of the ends.

The smooth surface produced by the abrasive cut-off wheel was very satisfactory for the necessary measuring which was to be performed, for positioning in the testing jig and for preventing the possible initiation of edge cracks due to roughness. Grinding one surface removed the mill scale in preparation for the automatic deposition of a 6-in. bead along the longitudinal axis of this surface. With the exception of one group of specimens prepared with a high value of weld energy input using $^1/_4$-in. diam E6016 electrode, all beads were deposited with $^3/_{16}$-in. diam E6010 and E6016

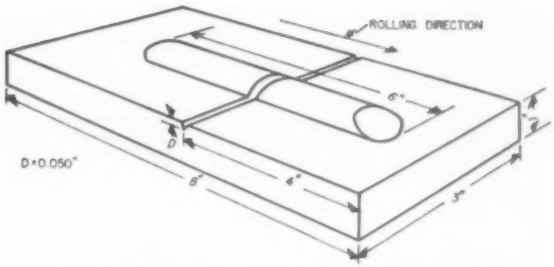

Fig. 1 Kinzel-type notched slow-bend specimen

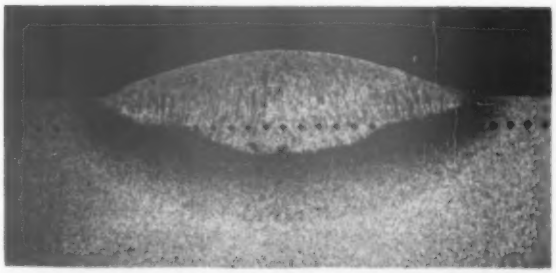

Fig. 2 Example of hardness traverse at depth of notch root of the Kinzel specimen. Steel 4201 welded with E6016 electrode at 55,000 j/in., 400° F postheat. 2% Nital etch. 3.5 ×

electrodes. Although the E6010 electrodes were used in the as-received condition, the E6016 electrodes were dehydrated previous to use by heating for 3 hr at 600° F to give a moisture content less than 0.1%. All electrodes were manufactured and supplied by the Arcrods Corp. A General Electric automatic welding head mounted on a General Electric automatic arc-welding travel carriage, previously described by others at Rensselaer,[9] was used to feed the electrodes. The welding conditions which were used are given in Table 1. The arc voltage, arc amperage and arc wattage were continuously recorded with Esterline-Angus recording equipment. Connections were made at the electrode for measuring both arc voltage and wattage. Preheating, postheating and dehydrating operations were done in a circulating-air furnace. The preheat temperatures were checked before welding with a contact-type pyrometer.

Table 1—Welding Conditions Used

Electrode type	E6016	E6010	E6016	E6016
Electrode diam, in.	3/16	3/16	1/4	3/16
Current, d-c amp.	220	225	260†	220
Voltage, v.	27	25	28	25
Welding speed, ipm	6.5	6.25	3.9	14.0
Energy input, j/in.*	55,000	55,000	113,000	23,800

* j/in. = joules/in. = $\frac{\text{arc volts} \times \text{arc amperes}}{\text{travel speed in in./sec}}$

† At the lower end of the recommended current range.

Following the welding and heat-treating operations, the samples were notched along the transverse axis of the welded surface in accordance with the techniques used by Kinzel. An illustration of the final sample is given in Fig. 1. The root of this notch traverses the unaffected plate, the heat-affected zone and the deposited weld metal, as shown in Fig. 2. Before testing, the sample width was measured 1/32 in. below the root of the notch to a precision of 0.001 in. This measurement was later used in determining the amount of lateral contraction experienced by the sample during testing.

TESTING EQUIPMENT AND PROCEDURE

Except for minor modifications, the equipment used to load the Kinzel notched slow-bend samples was similar to that described by Kinzel.[5] Two hardened-steel rolls, mounted on a welded framework, were used to support the specimens within an insulated steel testing container. These 1-in. diam testing rolls, notched circumferentially to accept the weld bead, were mounted with their axes 6 1/2 in. apart. The roll separation was increased from the 4 1/2 in. used by Kinzel to permit the fracture of the 1-in. samples with the limited load of 60,000 lb produced by the available testing equipment. The heat-insulated testing chamber was designed to contain liquid media for the regulation of the testing temperatures of the samples. Mixtures of dry ice and alcohol were used to attain temperatures below room temperature and heated water was used for testing to 212° F. A copper-Constantan thermocouple was used to determine the temperature of the liquid baths to within 0.1° F.

The insulated testing chamber and the loading ram were mounted on a hydraulically operated universal testing machine having a maximum capacity of 60,000 lb. The testing machine was adjusted within ±5% for a ram speed of 1 ipm during testing. After loading the sample to destruction in accordance with the Kinzel procedure, vernier calipers were used to determine the width of the sample 1/32 in. below the notch at the fracture surface to the nearest 0.001 in. The percent change in width at this position was calculated and recorded as percent lateral contraction.

The testing temperature at which a 1 and a 2% lateral contraction occurred was obtained from a plot of lateral contraction as a function of testing temperature for each condition investigated. This temperature, called transition temperature, was used to compare the ductility of the various welded and unwelded specimens. Kinzel adopted the testing temperature at which 1% lateral contraction occurred as his criterion for ductility since, with a rate of loading of 1 ipm, this criterion "broadly corresponds to the deformation measured in service failures at the section near the end of cracks which stop propagating." The 2% criterion was also used in the present investigation since the rate of change in lateral contraction with testing temperature was small in some cases in the region of 1%, so that a precise evaluation of transition temperature was difficult. The 2% lateral contraction corre-

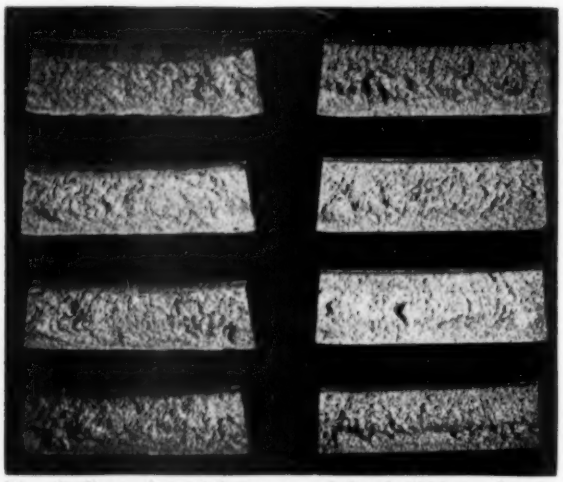

Fig. 3 Examples of fractures of Steel A201 in the as-received condition. Testing temperatures and lateral contractions at failure are given

T., °F.	L.C., %	T., °F	L.C., %
105	5.1	−2	3.2
68	4.8	−13	2.9
31	4.7	−38	2.4
16	4.2	−68	2.1

sponded in most cases to the lower end of the steep portion of the lateral contraction-temperature curve.

MATERIALS

In Part I of this investigation, three plain-carbon silicon-killed steels, supplied as 1-in. plate, were used. The composition and mechanical properties of these steels, supplied according to ASTM specifications, are listed in Tables 2 and 3.

Table 2—Composition of Steels Studied

	A212	*A201*	*A285*
C	0.25	0.19	0.16
Mn	0.86	0.55	0.61
P	0.016	0.016	0.014
S	0.026	0.028	0.022
Si	0.24	0.22	0.18
Ni	0.07	0.09	0.06
Cr	0.04	0.05	0.03
Mo	0.01	0.01	0.02
Cu	0.12	0.08	0.10
Al	0.008	0.007	0.013

Table 3—Mechanical Properties of Steels Studied

	A212	*A201*	*A285*
Yield point, psi	39,450	42,320	37,580
Tensile strength, psi	76,760	68,620	62,665
Elongation, % in 8 in.	25.2	25.2	27.7

TREATMENT OF DATA

As previously mentioned in the discussion of testing procedure, the percent lateral contraction at the testing temperature was determined for all samples tested.

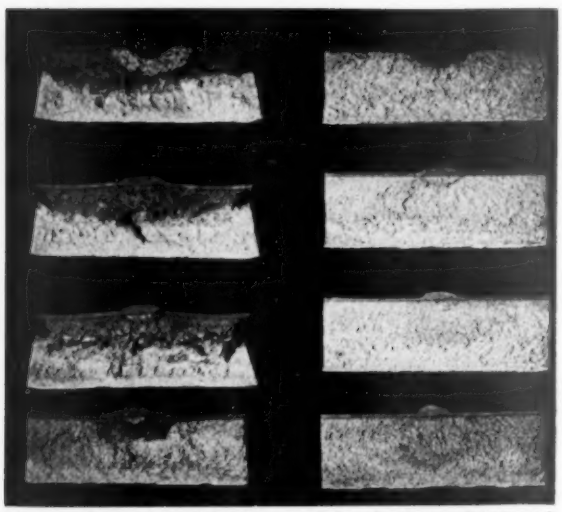

Fig. 4 Examples of fractures of Steel A201 welded with E6010 electrodes at 55,000 j/in. Testing temperatures and lateral contractions at failure are given

T., °F	L.C., %	T., °F	L.C., %
122	5.2	78	1.3
121	5.0	61	0.6
108	4.8	42	0.5
95	2.6	15	0.4

In order to provide the greatest amount of useful information, the percent lateral contraction of the samples was plotted as a function of the testing temperature. Several curves were included in the same figure whenever it was felt that such treatment would expedite their evaluation.

For example, Fig. 7 includes the lateral contraction curves as a function of testing temperature for the as-received; as-welded; preheated and welded; welded

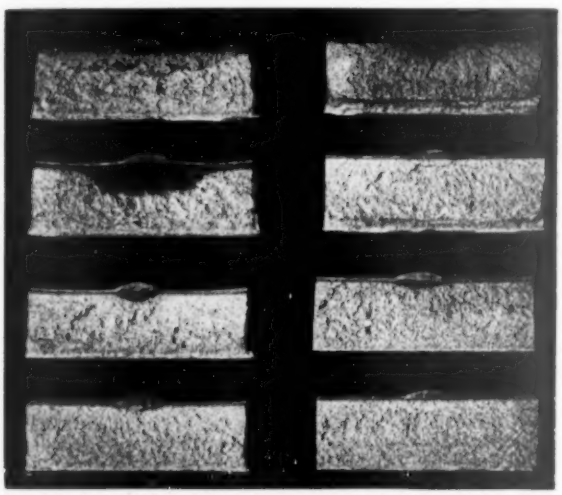

Fig. 5 Examples of fractures of Steel A201 welded with E6016 electrodes at 55,000 j/in. Testing temperatures and lateral contractions at failure are given

T., °F	L.C., %	T., °F	L.C., %
111	4.6	82	1.3
109	3.7	68	1.2
103	2.9	15	0.7
86	1.9	14	0.5

and postheated; and preheated, welded and postheated samples of A212 steel using E6010 and E6016 electrodes. Assuming 2% lateral contraction as the criterion of ductility, the relative behaviors of the steels can be evaluated from the temperatures at which the 2% lateral contractions occur. For example, the solid line, indicating the 400° F preheat treatment of the A212 steel welded with both the E6010 and E6016 electrodes, intercepts the point of 2% lateral contraction at 90° F. The curve indicating the testing of the as-received plate intercepts the point of 2% lateral contraction at −50° F. A comparison of these temperatures tells us that, at this criterion of ductility the as-received plate at −50° F will be as ductile as the steel welded with a 400° F preheat, tested at 90° F.

Hardness determinations, made with a Vickers hardness tester at a level 0.050 in. below the welded surface of the plate as shown in Fig. 2, were plotted as a function of their distance from the weld center line. These traverses show a peak hardness at the coarse-grained region of the heat-affected zone adjacent to the weld bead. As the distance from the weld increases, the grain size decreases and the steel becomes softer. The distance of the peak hardness from the weld centerline is one half the width of the molten material which formed the weld nugget at the level of the root of the notch. The width of the heat-affected zone at the root of the notch is the distance along the traverse from the peak hardness to the point at which the hardness values drop to the hardness of the prime plate. As with the lateral contraction data, several curves were included in the same figure whenever it was felt that such treatment would expedite their evaluation. For example, the hardness traverse of the as-welded A212 steel in Fig. 12 shows that the fusion zone at 0.050 in. below the plate surface is 0.60 in. wide and that the heat-affected zone occupies approximately 0.28 in. on either side of this fusion zone. The width of the heat-affected zone is measured from the position of peak hardness, VPN 260 at 0.29 in., to the position at which the hardness value drops to the hardness of the prime plate, VPN 150 at 0.57 in.

DISCUSSION OF RESULTS

The discussion of results has been subdivided under the following headings:

1. The Effects of Chemical Composition of the Steel.
2. The Effect of Electrode Type.
3. The Effects of Preheat, Postheat and Stress-Relief Heat Treatment.
4. The Effect of Energy Input.
5. The Effect of Prestraining.

Each of these topics will be considered below in the order listed, and summary curves will be presented wherever possible to simplify the discussion.

1. *The Effects of Chemical Composition of the Steel.* Vanderbeck[10] has shown that deoxidation practice has a considerable effect upon the transition temperature of

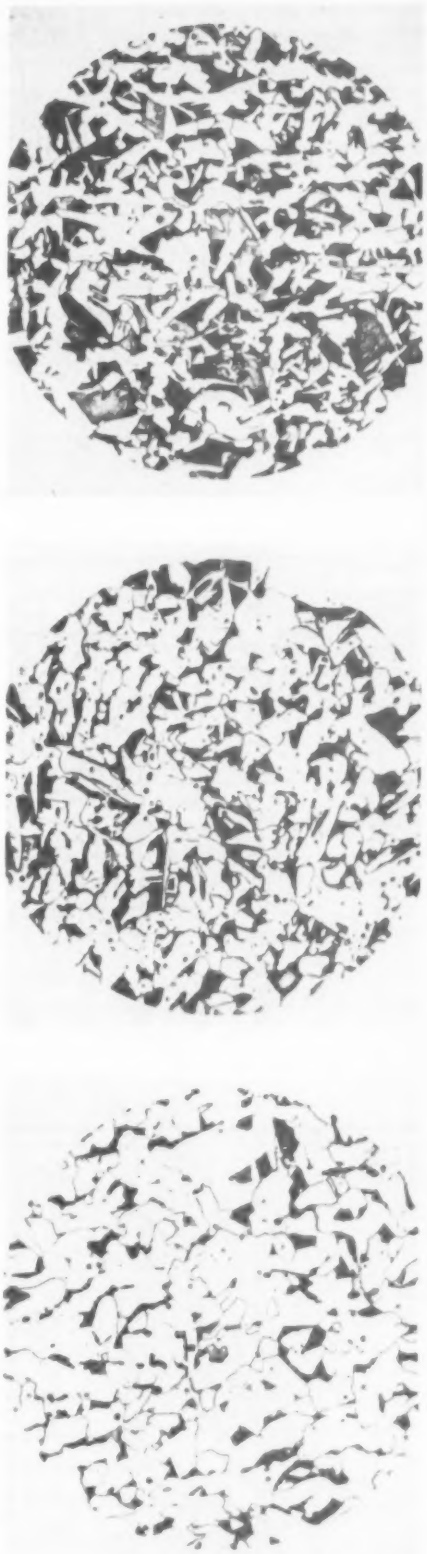

Fig. 6 As-received microstructures of the 1-in. plate used in the Kinzel test. 2% Nital etch. 100 ×

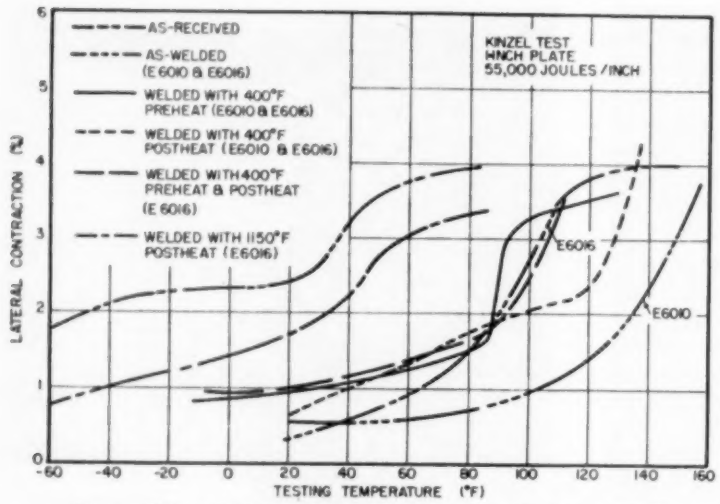

Fig. 7 Effects of electrodes and heat treatments, Steel A212

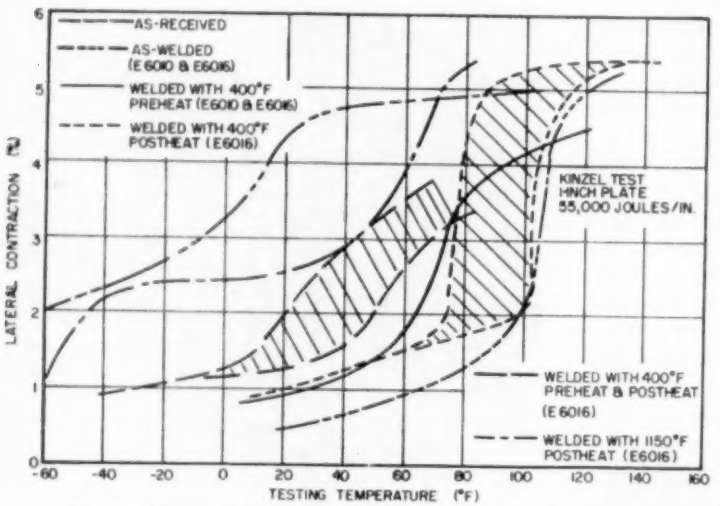

Fig. 8 Effects of electrodes and heat treatments, Steel A201

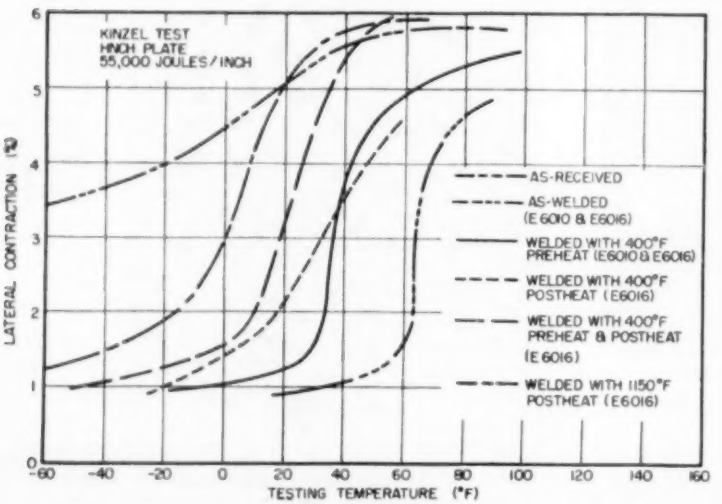

Fig. 9 Effects of electrodes and heat treatments, Steel A285

steels as tested in impact. But he and others have also shown that carbon, manganese and phosphorus can have an even greater effect upon the ductility of a steel than the deoxidation practice. The ferrite grain size was also shown to have an effect upon the embrittlement of a steel. Another factor of embrittlement, the carbide distribution of the steel as affected by the cooling rate through the transformation region, has been shown by Enlund to have a greater influence upon the ductility of a weldment than the deoxidation practice.

Photomicrographs of 100× of the steels listed in Table 2 are included in Fig. 6 and show the as-received microstructure. An examination of the photomicrographs will reveal that, although there is only a slight variation in the as-received grain size of these steels, there is a considerable variation in the amount of free ferrite. The difference in the ferrite content of the A201 and A285 steels is greater than one would expect from the composition variations of the two steels. For this reason, and because of differences of mechanical properties shown in Table 3, it is suspected that the two heats had different finishing temperatures. The low-carbon and manganese content of the A285 stock is also of advantage in retaining ductility under adverse conditions of loading.

Figures 7–9 show the effects of various heat treatments upon the transition behavior, as determined by the Kinzel test, for welded A212, A201 and A285 steels, respectively, and a curve representing the transition behavior of the as-received plate has been included for comparison in each case. Figure 10*A* is a summary plot compiled from Figs. 7–9, and compares the transition temperature of each steel, obtained by a 2% lateral contraction criterion for the various heat treatments studied, while Fig. 10*B* summarizes data for 1% lateral contraction. As may be seen by inspection of Figs. 10*A* and *B*, the A285 shows the greatest ductility, the A212 the least, while the A201 occupies an intermediate position. The order of ductility exhibited by these three steels is to be expected in view of the differences in microstructure and composition outlined in the previous para-

graph. The order of ductility of these three steels cannot be attributed to any one factor, but must be considered as the product of many variables in composition and rolling practice.

The welding process produces a considerable loss of ductility which is measured by a 140 to 190° F increase in the temperature of 1 or 2% lateral contraction. There is no basis for predicting the actual transition temperature by means of composition and microstructure of the steels since the variables are so numerous. It may be stated from an examination of Figs. 10*A* and 10*B* that welding does have a considerable effect upon the transition temperature of the 1-in. plate investigated and, qualitatively, that welding has a greater effect upon the transition temperature of the A201 and A212 than upon the A285 steel.

2. *Effect of Electrode Type.* Schaeffler and his collaborators,[14] in their review of the effects of hydrogen upon the mechanical properties of weld metal and welded samples, have given ample evidence to show that hydrogen does embrittle a structure. This evidence has been substantiated by the results of the present investigation, since, as shown previously in Figs. 7, 10*A* and 10*B*, the welds made in A212 plate with the cellulose-coated E6010 electrode and lime-coated E6016 electrode behaved differently in the as-welded condition. In the as-welded condition, the E6010 weldments had a transition temperature 40 to 45° F higher than those welded with the low-hydrogen E6016 electrode. The improvement of the E6010 deposit by all other conditions of heat treatment which were investigated is sufficient to make it comparable to the E6016 deposit.

The A201 and A285 steels, as illustrated in Figs. 8, 9, 10*A* and 10*B*, showed no differences in transition temperature when welded with the E6010 or E6016 series of electrodes. Even so, evidence of the presence of hydrogen in the cellulose electrode group was present, as may be seen by examination of Figs. 3, 4 and 5, which exhibit Kinzel-test fractures in A201 steel in the as-received, as-welded with E6010 and the as-welded with E6016 conditions, respectively. Figure 4 includes a photograph of a sample welded with E6010, and tested at 122° F, which exhibits a wide band of brittle fracture completely surrounded by ductile material. Although the lateral contraction measurements do not indicate a difference in ductility, the location of the brittle fracture and the behavior of the sample during test indicate that some hydrogen embrittlement is probably present. The area of brittle fracture evident in the above sample is located in the region directly beneath the weld bead where hydrogen is most likely to be concentrated. Furthermore, a sudden drop in the load was observed during the testing of this sample as

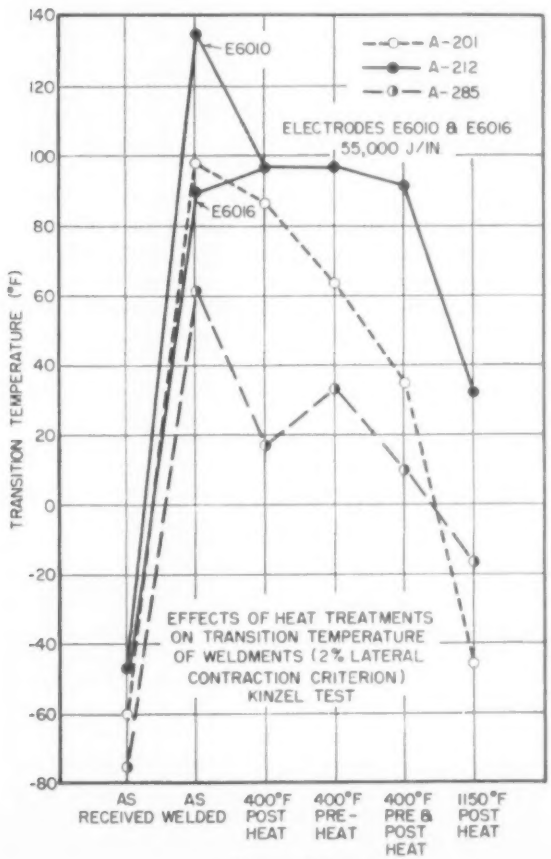

Figure 10A

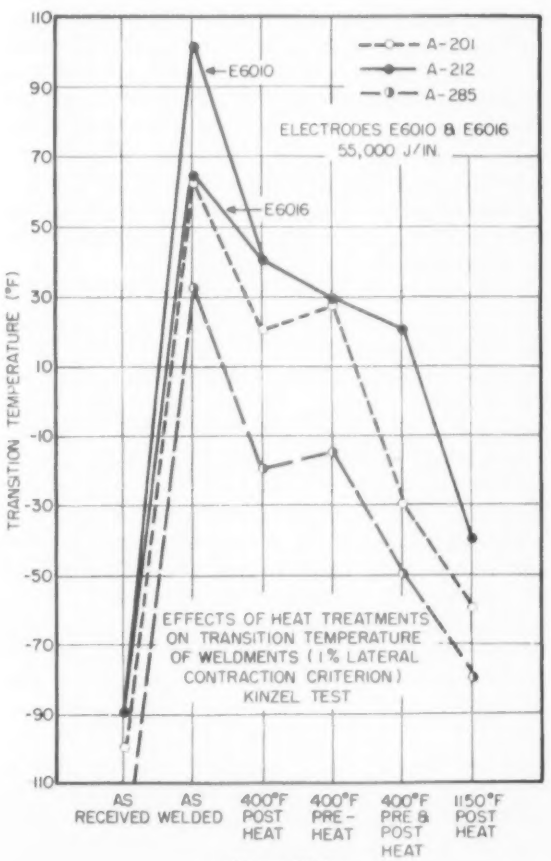

Figure 10B

the fracture propagated through this area. In spite of the initiation of this brittle failure, the base metal was sufficiently insensitive to the condition of stress at the root of the crack to prevent propagation of a brittle failure. This condition was never observed with the A212 samples which, because of their higher carbon content, were more notch sensitive. As a result of this limited study of steel and electrodes, it appears that plain-carbon steels with low carbon and low manganese contents, i.e., steels of low hardenability, would not be sensitive to the hydrogen content of an electrode coating. The more hardenable steels would be more likely to display such sensitivity. The utilization of proper heat treatments appears to alleviate this condition by permitting the rapid diffusion and escape of hydrogen from the weldment.

3. *The Effects of Preheat, Postheat and Stress-Relief Heat Treatment.* The effects of a 400° F preheat, 24-hr 400° F postheat, a combination of the preheat and postheat treatments, and the effects of a 1-hr stress-relief heat treatment at 1150° F were investigated. From a comparison of Figs. 7–10, it may be seen that the 1150° F stress-relief heat treatment does more to improve the ductility of a weldment than any of the other treatments studied. Part of this improvement may be explained on the basis of the residual stresses present in the as-welded samples which are relieved by the 1150° F treatment but are affected only slightly by the 400° F heat treatment. The residual stress state in the as-welded specimens was evident from the distortion present, which made the machining of notches to the desired precision difficult. The 1150° F treatment is also of considerable benefit to those regions of the heat-affected zone heated by welding to a maximum temperature ranging from 800 to 1200° F. This beneficial effect might very likely result from overaging in these subcritical regions which are susceptible to the phenomenon of strain aging.

In summary, from Fig. 10*B*, the effect of 400° F preheat was to lower the as-welded transition temperature approximately 40° F for both E6010 and E6016 electrodes with the A201 and A285 steels, the steels of lower carbon content. For the A212, the steel of highest carbon content, the effect of 400° F preheat was to lower the transition temperature approximately 80° F for the E6010 electrode and 40° F for the E6016 electrode. The effect of a 24-hr postheat at 400° F in improving the as-welded transition temperature was approximately equivalent to that of a 400° F preheat for both electrode types with all three steels. For a combination of 400° F preheat and 400° F postheat, the as-welded transition temperature was lowered approximately 85° F for both electrode types with the A201 and the A285, the steels of lower carbon content. For the A212, the steel of highest carbon content, the effect of this combination treatment was to lower the transition temperature approximately 85° F for the E6010 electrode and 45° F for the E6016 electrode. The 1-hr stress-relief treatment at 1150° F lowered the as welded transition temperature approximately 110 to 140° F. These temperatures are within 40 to 50° F of the transition temperature of the as-received plate material.

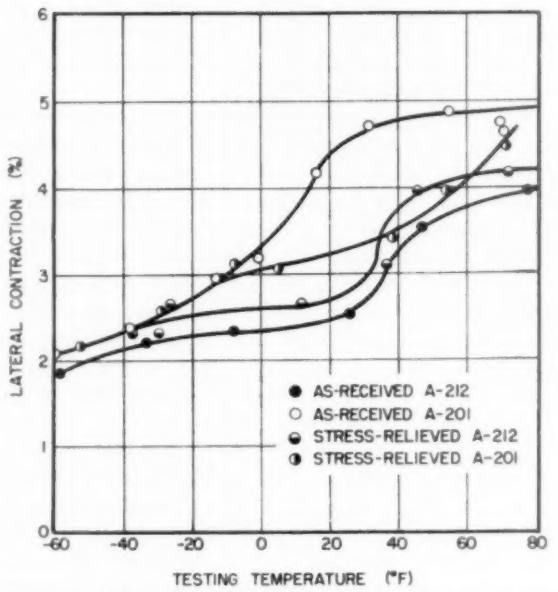

Fig. 11. Effect of stress relief at 1150° F on as-received plate, Kinzel test

It seems unlikely that the higher ductility observed following 1150° F stress relief resulted from metallurgical improvement of the prime plate, and data presented in Fig. 11 indicate that such a treatment may even have a deleterious effect, as is the case for the A201 steel. The same slight embrittlement by heating the A201 as-received plate to 1150° F was shown by Cubitt-Smith.[18]

Figure 12, a plot of Vickers hardness at the level of the root of the notch vs. distance from the weld centerline, shows that the 400° F postheat treatment for 24 hr had no effect in changing the hardness level at any point along the traverse. A 400° F preheat lowered the hardness throughout the heat-affected zone by retarding the cooling rates through the regions of transformation. A similar reduction of hardness was noted

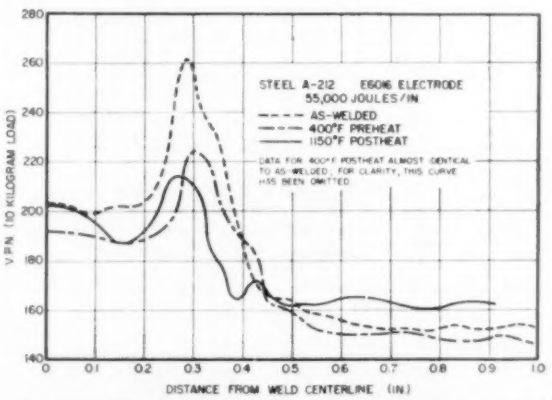
VPN (10 KILOGRAM LOAD)
DISTANCE FROM WELD CENTERLINE (IN.)
STEEL A-212 E6016 ELECTRODE
55,000 JOULES/IN
AS-WELDED
400°F PREHEAT
1150°F POSTHEAT
DATA FOR 400°F POSTHEAT ALMOST IDENTICAL TO AS-WELDED. FOR CLARITY, THIS CURVE HAS BEEN OMITTED

Fig. 12. Effect of heat treatment on hardness, VPN, Vickers Pyramid Numeral, is the same as DPH, Diamond Pyramid Hardness

in all three steels when preheat was employed. The 1-hr 1150° F post-treatment had a very noticeable effect upon the hardness, as shown in Fig. 12. Although this hardness traverse is for the A212 steel, all three steels showed a similar, proportional decrease in hardness along the traverse. Little change in the distribution of the carbides can be noted after heating to 1150° F, but indications of spheroidization may sometimes be noted. It is unlikely that a change in the residual stress state could produce such a marked reduction in hardness. One explanation of the reduction in hardness may be based upon the fact that all of the regions of a heat-affected zone heated above 1750° F, are Widmanstatten in nature. The Widmanstatten structure may be thought of as an oriented material, since it is a subcritical type of transformation. With reheating to 1150° F, a relaxation of the lattice due to diffusion of lattice defects and dislocations might produce a less highly strained and, therefore, softer material.

As previously discussed from Fig. 10*B*, all three steels showed a trend for improvement with the application of a preheat or a postheat, and, a more marked improvement with a combination treatment at 400° F. This behavior is to be expected since the preheat should lower the maximum hardness of the weldment and the postheat treatment should slightly improve the residual stress state and cause diffusion of hydrogen from the heat-affected regions.

4. *The Effect of Energy Input.* In order to determine the relative influence of preheat and cooling rate upon the ultimate ductility of a preheated weldment, four sets of welding conditions, listed in Table 4, were investigated using E6016 electrodes.

Table 4—Cooling Rates at Selected Welding Conditions

Welding conditions	*Cooling rate at 1000° F, °F/sec.*
113,000 j/in., no preheat	23
55,000 j/in., 400° F preheat	23
55,000 j/in., no preheat	58
23,800 j/in., 400° F preheat	58

The maximum cooling rates at 1000° F for a weld energy input of 55,000 j/in. on 1-in. plate were calculated[9] to be 58° F/sec without a preheat and 23° F/sec. with a 400° F preheat. Similar calculations showed that a cooling rate of 23° F/sec would be obtained with a weld energy input of 113,000 j/in. without a preheat, and that a cooling rate of 58° F/sec would be obtained with a weld energy input of 23,800 j/in. with a preheat of 400° F. Steel A212 was selected for this experiment since it had the greatest hardenability and so would be expected to show best the effects of cooling rates.

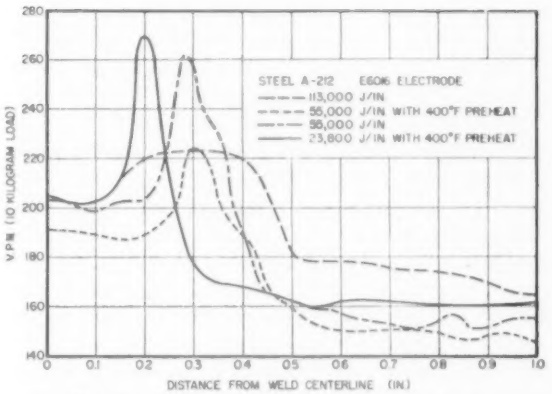

Fig. 13 Effect of energy input on hardness

A comparison of the hardness traverses of Fig. 13 shows that the two conditions with calculated maximum cooling rates of 58° F/sec have similar peak hardnesses. Furthermore, the peak hardness was considerably greater than that found in the test specimens having the slower rate of cooling. Samples having as a maximum cooling rate 23° F/sec exhibited equal peak hardnesses in both the preheated and room temperature weldments.

Figure 14 summarizes the influence of preheat and cooling rate on lateral contraction as a function of the testing temperature. Using a 1% lateral contraction criterion for ductility, it may be seen that both groups of specimens made without preheat had a transition temperature of 60° F, whereas both groups made with 400° F preheat had a transition temperature of 25° F. From these results, it is apparent that preheat is effective in lowering the transition temperature, and furthermore, that the effect of energy input is negligible.

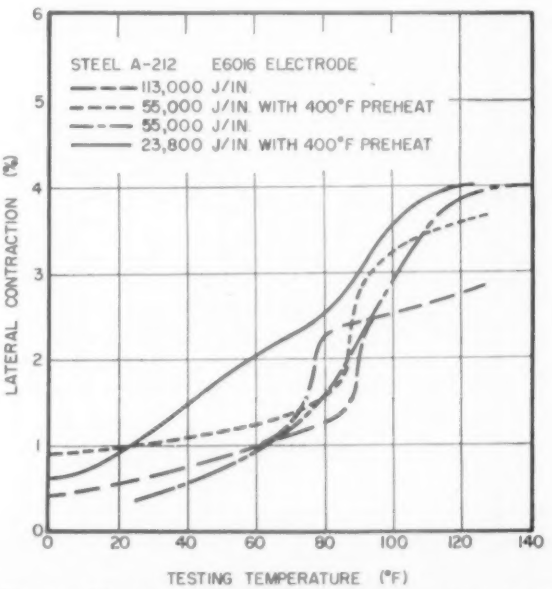

Fig. 14 Effect of energy input on ductility, Kinzel test

However, it should be realized that if lower energy inputs and higher cooling rates had been investigated, less ductile heat-affected structures with higher transition temperatures would have resulted.

The different welding conditions which result in equal cooling rates at 1000° F do not necessarily result in equal cooling rates at temperatures lower than 1000° F. The cooling rate through 400° F has been suspected by Flanigan[20] as being of great significance to the ultimate ductility of a structure. In this case, it appears that the two groups of samples produced with a 400° F preheat have improved ductility due to the slower low-temperature cooling rates.

5. *The Effect of Prestraining.* Although Stout[21] and Flanigan[22] have shown that strain aging after welding has a deleterious effect upon the ductility of a weldment, an experiment was performed to determine the effect of welding upon the ductility of a prestrained sample. Steel A285 was selected since Christoffel[23] had shown that this steel was susceptible to strain aging.

Two groups of unwelded Kinzel samples were bent in the testing jig at room temperature to a permanent set of 4 deg. One of these groups was aged at 400° F for 3 hr, the other was welded on the tension side of the prestrained specimen with E6016 electrode and an energy input of 55,000 j/in. Both groups were tested within 24 hr after preparation, with the direction of bending corresponding to the direction of prestraining. From Fig. 15, it is obvious that the A285 steel is susceptible to strain aging since the curve for the sample prestrained and aged at 400° F for 3 hr shows a loss of ductility at every testing temperature when compared to the as-received plate. The improvement in the ductility of the prestrained, welded sample without aging compared to the ductility of the as-welded specimen is to be noted. The only logical explanation for this improvement seems to be that the residual stress state produced by welding upon the prestrained plate has caused a residual stress pattern which makes the notch less effective in initiating fracture.

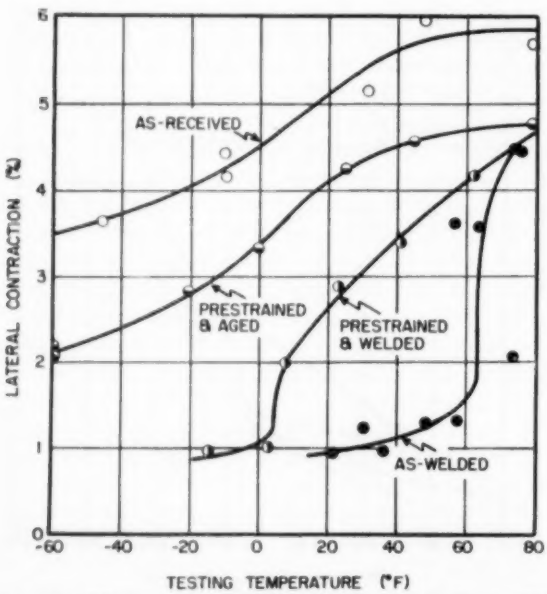

Fig. 15 Effect of prestraining, Kinzel test, Steel A285

Fig. 16 Fracture surface and associated macrostructure of Steel A212 welded at 400° F with E6016 electrode and postheat treated at 400° F. Broken at 75° F with lateral contraction of 1.90%. Lower figure with 2% Nital etch. 3 ×

Part II. The Effects of Thermal Cycles of Welding

INTRODUCTION

An examination of the fractures produced by the Kinzel notched slow-bend tests showed that in many cases brittle fractures would not be propagated throughout the entire sample. Certain regions would change the mode of fracture from brittle to ductile, and, with the proper conditions of testing, cause failure to continue in a ductile manner. In other cases, as illustrated in Fig. 16, the propagation of a brittle fracture would merely be impeded by a ductile region. The resulting appearance would be that of an island of ductile material surrounded by brittle material. Obviously, the metallurgical characteristics of all regions would have a considerable effect upon the over-all ductility of a weldment.

Although some effort has been made to compare the relative properties of these structures,[16, 17] much research remains to be done. The marked reduction of hardness in the heat-affected zone produced by an 1150° F stress-relief heat treatment is difficult to rationalize. The effects of slower cooling rates accompanying the application of preheat are not completely under-

stood. The effect of hydrogen on the various microstructures formed in welding should also be studied. In addition, the behavior of the heat-affected microstructures under the stress conditions found at the roots of notches should be analyzed, since some structures may be more resistant than others to the initiation or propagation of a crack.

In order to investigate the properties of these structures, it is necessary to prepare samples in which these structures are reproduced in sufficient volume for testing. Nippes and Savage[17] have developed a high-speed time-temperature controller which reproduces the thermal cycles associated with any desired region of the heat-affected zone. Samples 3 in. long with a cross section approximately $^1/_2$ in. square are heated by a controlled current to reproduce any thermal cycle in a $^1/_4$-in. band which is perpendicular to the longitudinal axis of the sample.

Impact testing does not provide a universally satisfactory measure of resistance to fracture. For example, it does not show the effects of hydrogen embrittlement resulting from straining. Herres[24] has shown that hydrogen-plated bars would show greater ductility when tested in impact loading than with slow pulling in tension. An additional fault lies in the failure of the standard impact test to differentiate between the energy necessary to reach the ultimate strength of a sample and the energy absorbed after the initiation of fracture. In other words, the standard impact test does not give any indication of the energy necessary to initiate fracture, nor does it differentiate between a sample which is tough because it has a very high yield strength or one which is tough by virtue of great ductility.

For these reasons, it was decided to develop a device to permit the testing of samples which had been heat treated to duplicate thermal cycles. The test equipment was designed to incorporate the following features:

1. Reproduce load-deflection curves of the testing process.
2. Have a slow ram speed so that the effects of hydrogen might be studied.
3. Permit the testing of samples in liquid media at temperatures as low as that of liquid nitrogen.

It was also decided to investigate the application of the Schnadt-type sample[25, 26] to such testing. The Schnadt sample is an adaptation of the Charpy sample in which the regions of compression are removed by drilling and replaced with a hardened pin about which the remaining sample revolves when loaded. Schnadt has also made provisions for varying the notch geometry of the samples. The Schnadt test was attractive because:

1. This bend test would require only a small deflection to fracture.
2. Fracture would occur even at conditions of high ductility.
3. Only a small percentage of energy is absorbed in compressive deformation.
4. Variations in the notch geometry would permit the study of notch sensitivity of a material.

In order to investigate the sensitivity of such testing it was decided to study the effects of various thermal treatments on a series of steels containing four types of notches.

DESIGN OF SAMPLES

The samples described by Schnadt were modified slightly by employing standard contour milling cutters readily available in this country to machine the notches. Further, stress-concentration factors were used to describe the samples instead of Schnadt's complex terminology. The stress concentration factor, b, is defined as the ratio of the maximum longitudinal stress at the base of a notch to the average stress in the unnotched section. The sharper or deeper the notch, the greater will be the principal stresses just below its base. With the rest of the sample geometry and applied load constant, the magnitude of the shear stress will also increase as the principal stresses increase. Coker and Filon[2] determined by photoelastic measurements the quantitative effect of notch geometry on the concentration of the longitudinal tensile stress at the base of a Charpy test bar. It was shown that the stress-concentration factor is directly related to the ratio of the square root of the depth of the notch to the radius of the notch. For a notch depth of 0.079 in., notch radii, as indicated in Fig. 17, were calculated which

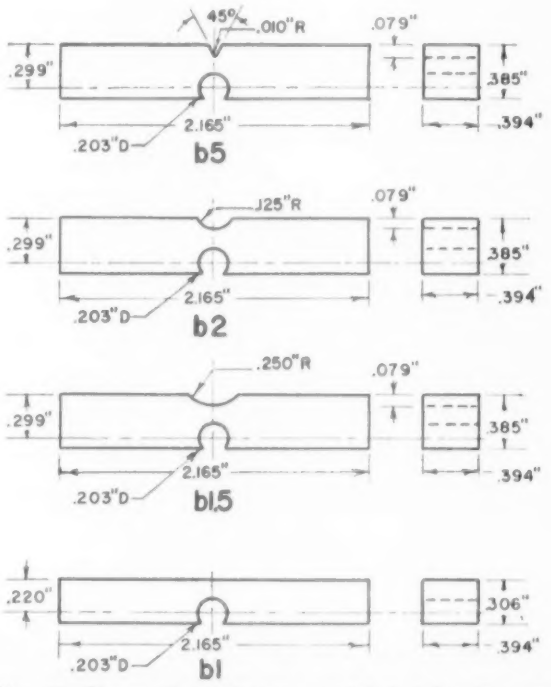

Fig. 17 Types of specimens, modified Schnadt test. b5 indicates a stress concentration factor of 5; b2, a factor of 2

would produce stress concentration factors of 1, 1.5, 2 and 5. A stress concentration factor of 5 is produced by the standard Charpy "V" notch, while a stress concentration factor of 1 is produced by complete removal of metal to the depth of the notch, a so-called "infinite" radius.

Samples used in this portion of the investigation were machined from $^1/_2$-in. plate with the longitudinal axis parallel to the rolling direction and the notch axis perpendicular to the rolled surface. This orientation of the notch was chosen to insure that the notch would traverse as much of the depth of the plate as possible and to prevent tearing during fracture from the banding of inclusions or ferrite. The samples were rough machined to a 0.404-in. square cross section and heat treated to duplicate the desired thermal cycles of welding using the techniques described by Nippes and Savage.[17] Following this heat treatment, the samples were finished to size with a liquid-cooled surface grinder. A drilling jig was used to locate the hole for the hardened steel pin in the compression area of each sample, and then the samples were notched as indicated in Fig. 17. The 0.125-in. and 0.250-in. radii were finished with hones of matching radii in order that the machining marks would be removed. The hones were rotated in a drill press during polishing so that the hone marks would be parallel to the axis of the sample. Hardened drill-rod pins, machined with a diameter 0.0005 in. less than the diameter of drilled holes, were inserted in preparation for testing. The dimensions of finished samples are illustrated in Fig. 17.

DESIGN OF TESTING EQUIPMENT

As stated previously, the testing device should be of the slow-bend type, it should be able to maintain temperatures from that of liquid nitrogen to temperatures above room temperature and it should provide a measure of load as a function of deflection. In order to determine the load-deflection curves in the most rapid and convenient manner, it was desirable to have the load and deflection measurements recorded continuously. The mechanism employed is illustrated in Figs. 18 to 20.

The sample to be tested was supported by two anvils mounted in an insulated housing. This unit also contained a coiled copper tube which served as a heat exchanger for cooling the liquid medium used as a bath for the samples. For temperatures between $-100°$ F and room temperature, mixtures of dry ice and alcohol were used to cool the samples. For temperatures between $-240°$ F and $-100°$ F, the liquid medium was a commercial grade of pentane, which was cooled by liquid nitrogen forced through the heat-exchanger coil. The liquid nitrogen was forced from a container by means of nitrogen gas at a pressure of 20 psi. An expansion valve in the upper part of the coil permitted the liquid nitrogen to expand to atmospheric pressure producing a further lowering of temperature. Nitrogen gas was also used to agitate the pentane to produce better heat transfer and a more uniform bath temperature. The temperature in the immediate vicinity of the sample notch was measured with a thermocouple which entered the upper part of the container through a copper tube. Provision was also made for filling and draining the unit while in use in order that some temperature regulation could be obtained by adding warm pentane.

Load measurements were obtained as outlined below. The entire testing unit was supported with knife edges at the third points of a simply supported hardened-steel beam, as illustrated in Fig. 18. When the sample was loaded, the beam was deflected producing strain in its outer fibers proportional to the load. A voltage signal proportional to the strain was continuously obtained by means of type C-5 SR4 strain gages mounted on the supporting beam. These gages were connected in a bridge circuit, as illustrated in Fig. 21, so that a change in resistance would produce an unbalance in the bridge which could be recorded conveniently with an oscillograph galvanometer.

A cantilever beam attached to a fixed reference point was deflected at its free end by a shoulder attached to the loading ram. The output of a strain-

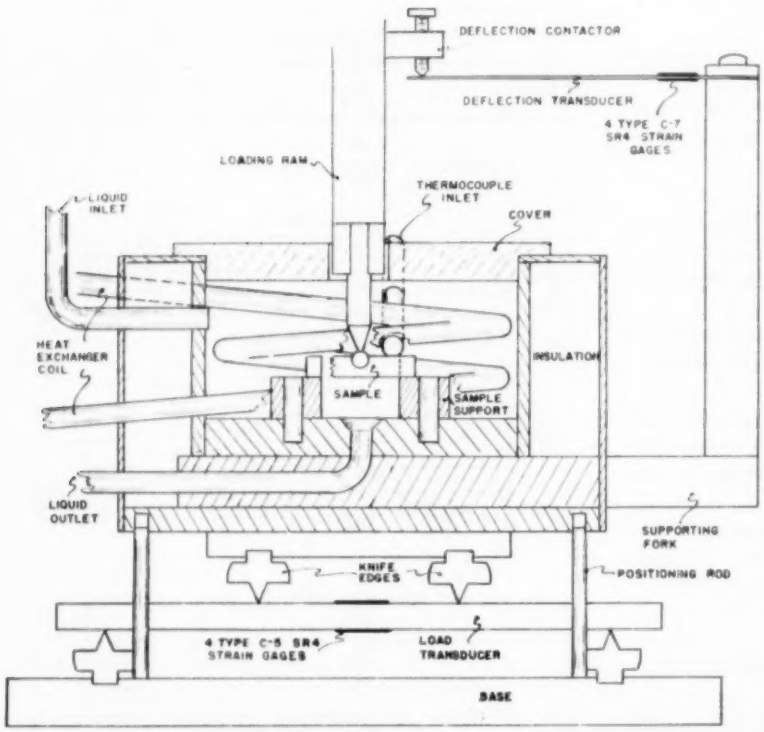

Fig. 18 Loading jig for the modified Schnadt test

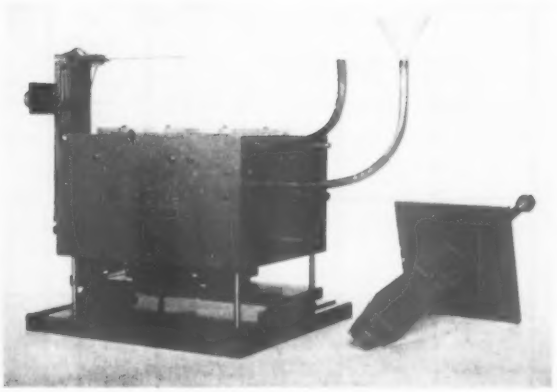

Fig. 19 Testing device

gage bridge mounted on the cantilever beam was used to obtain a continuous oscillograph record of the amount of strain produced in the beam during testing. From this record, the deflection produced in the specimen could be readily obtained by means of suitable calibration curves.

Since the voltages of unbalance from the strain-gage bridge were not sufficient to actuate the galvanometers contained in the General Electric oscillograph (Type PM-17-A1), a General Electric oscillator and amplifier unit (Cat. No. 9062833G2) was used to produce a signal of sufficient magnitude for the galvanometer as illustrated in Fig. 21. A variable autotransformer, connected in series with the oscillograph drive motor, was employed to control the speed of the recording medium, and a variable resistor in series with the recording lamp was used to adjust the light intensity for recording purposes. A timing trace of $^1/_5$- and 1-sec intervals was also added to the oscillograph records. From the oscillograph records the load as a function of deflection was plotted and the rate of loading was determined. Figure 22 shows a typical oscillogram, while typical examples of the load-deflection curves are shown in Fig. 23.

TESTING PROCEDURE

The sample was centered upon the anvils with its hardened pin upward. Following a 10-min interval for the sample to come to equilibrium with the bath, the testing load was applied to the specimen at the hardened steel pin at a rate of 2 ipm until fracture occurred. The area under the load-deflection curve for each specimen was determined with a planimeter, and the energy absorbed to destruction was calculated from this area. The percent lateral contraction of the specimen was determined by methods similar to those described for the Kinzel test in Part I of this report. The fracture appearance was noted and recorded as the percent brittle fracture. These data were used to plot curves showing lateral contraction, energy to failure and percent brittle fracture as a function of the testing temperature. From these curves were obtained the transition temperature for the ductility transition,

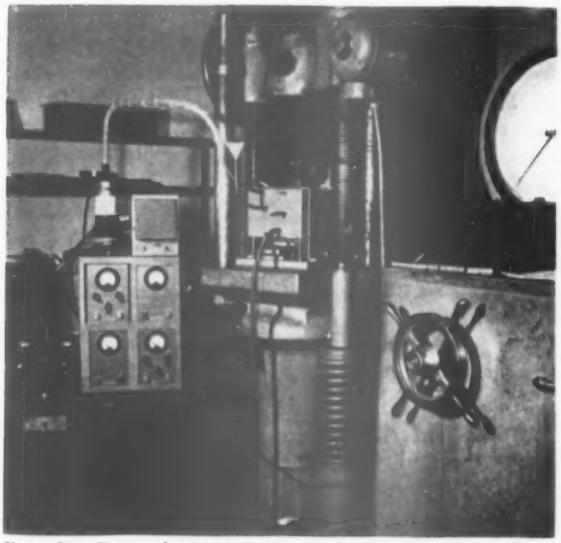

Fig. 20 General arrangement of equipment showing testing device, oscillograph and method of liquid nitrogen transfer

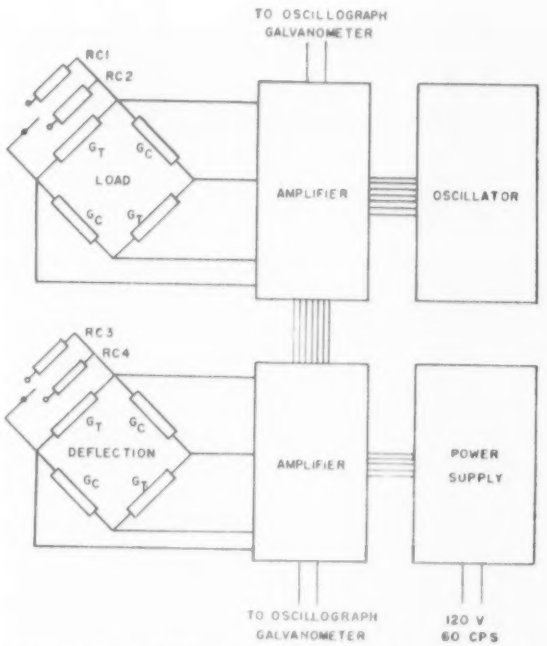

Fig. 21 Electrical circuit for load and deflection measurements

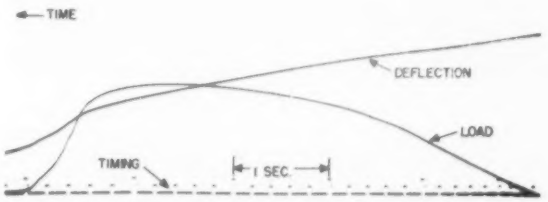

Fig. 22 A typical oscillograph record of a Schnadt-type sample being loaded to failure. Galvanometer traces of load, deflection and time are shown

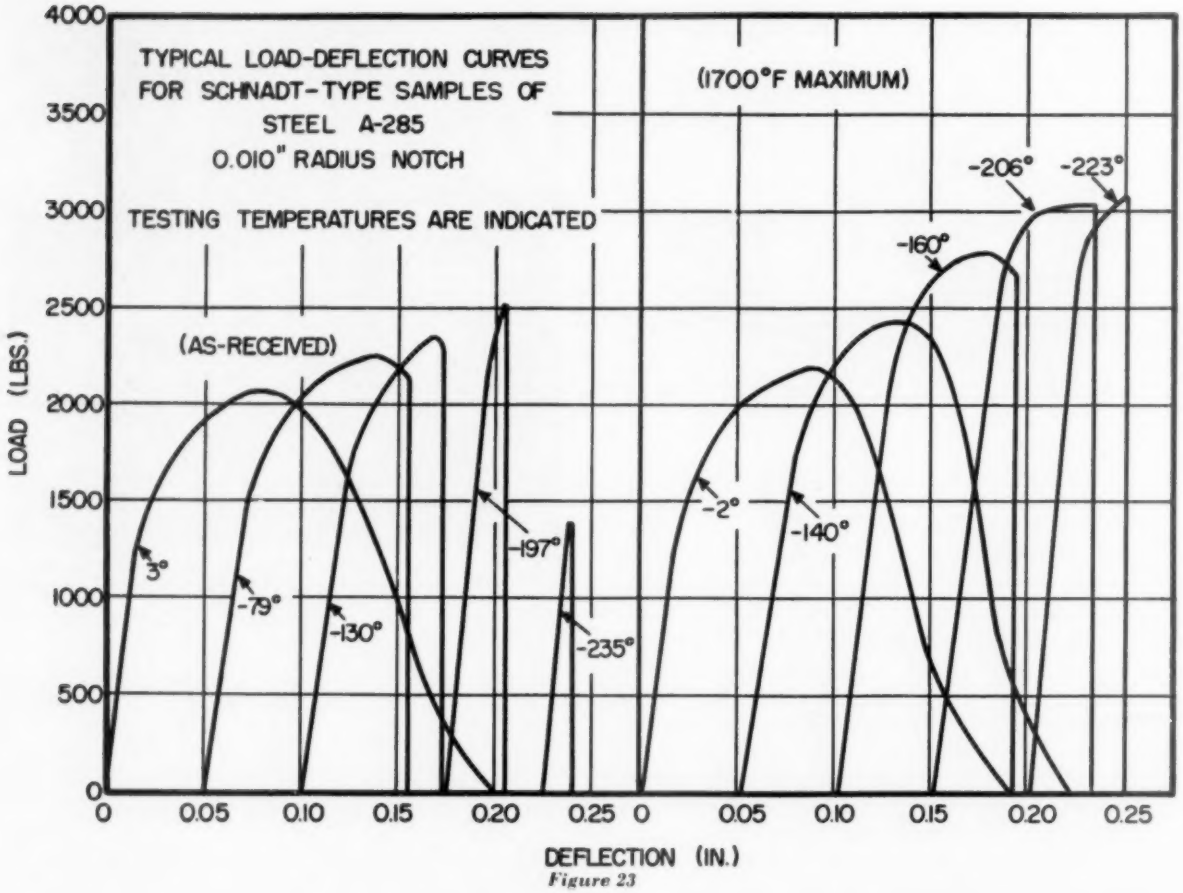

Figure 23

energy transition and the fracture transition. Photographs of typical fracture surfaces are illustrated in Figs. 24 to 26.

SELECTION OF THERMAL CYCLES

As a result of work previously conducted in this laboratory,[9, 28] it is possible to predict accurately the thermal cycles experienced by various locations in the vicinity of an electric arc weld for any given set of welding conditions. Previous investigators at Rensselaer have used this information to duplicate various microstructures found near an arc weld, using the time-temperature control device constructed by Nippes and Savage[17] so that studies of the impact behavior of these microstructures could be made. The present investigation chose to study the effect of metallurgical changes in the vicinity of an arc weld by applying the techniques of Nippes and Savage[17] to the production of Schnadt-test specimens.

For the present investigation, three steels were selected to permit a comparison of the effects of chemical composition, and four different thermal cycles were chosen to provide representative metallurgical changes in each steel. Table 5 summarizes the chemical composition of the three steels utilized in this phase of the investigation, and Table 6 summarizes the mechanical properties.

Table 5—Composition of Steels

	A212	*A201*	*A285*
C	0.26	0.16	0.18
Mn	0.67	0.56	0.53
P	0.017	0.18	0.014
S	0.031	0.025	0.024
Si	0.24	0.21	0.13
Ni	0.05	0.09	0.06
Mo	0.01	0.02	0.01
Cr	0.02	0.04	0.05
Cu	0.10	0.13	0.09
Al	0.006	0.008	0.011

Table 6—Mechanical Properties of Steel

	A212	*A201*	*A285*
Yield point, psi	42,930	38,010	35,560
Tensile strength, psi	75,790	63,590	61,620
Elongation, % in 8 in.	24.2	28.0	27.2

The ASTM grades of steels are similar in composition to those studied in the first part of this work. However, for ease of machining, $1/2$-in. plate was selected for preparation of the Schnadt samples. The 1- and $1/2$-in. plates were not produced from the same heats, and, therefore, differed in deoxidation and melting practice.

SELECTION OF THERMAL CYCLES

The nature of the metallurgical changes produced in the vicinity of an arc weld depends upon the peak temperature attained as a result of the welding operation and the heating and cooling rate incident to this peak temperature.

In general, it has been demonstrated that metallurgical changes in the vicinity of an arc weld can be classified in one of five categories:

1. A coarsened region, immediately adjacent to the fusion zone, where high peak temperatures produce a large austenitic grain size. Since the most rapid heating and cooling cycles are experienced in this region, the resulting microstructure exhibits a coarsened grain structure, usually Widmanstatten in character. The peak temperatures associated with this region range from about 1800° F to just below the melting temperature of the steel.

2. A region of total refinement, next removed from the coarse-grained region, in which the peak temperatures are just sufficient to produce complete transformation to austenite. Within this region, the austenitic grain size is extremely small, and therefore the resulting grain size of the transformation products exhibits total refinement. The peak temperatures associated with this region generally fall between 1550 and 1750° F.

3. A region of partial refinement next removed from the region of total refinement in which the peak temperature is able to produce only partial austenitization. Within this region, only areas rich in carbon (pearlitic areas) transform to austenite. The extent to which the transformation to austenite encroaches on the surrounding ferritic areas depends in a complex manner upon the actual peak temperatures, the distribution of the original carbides, and the effective time at temperature. Since only the areas experiencing transformation to austenite exhibit refinement in grain size, this area is known as the region of partial refinement. Stout and others[4] have demonstrated that the high effective carbon content of the regions transformed to austenite produces a localized increase in the hardenability and make these regions susceptible to embrittlement. The peak temperatures associated with this region are found between the effective values of the A_{c1} and the A_{c3} for the particular steel.

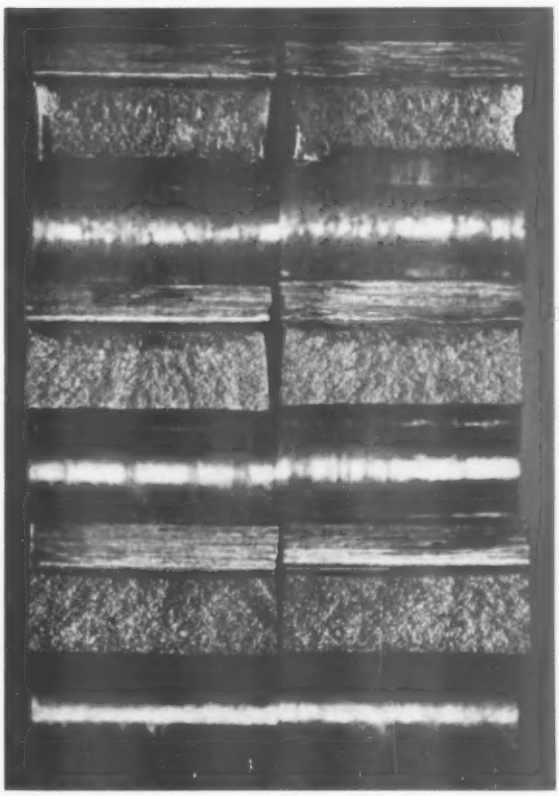

Fig. 24 Typical fractures for Schnadt-type samples containing notches with root radii of 0.010 in. Steel A285 with a maximum temperature of 1500° F. Testing temperatures and lateral contractions at failure are indicated. 4.0 ×

T_t, °F	L.C., %
− 47	7.8
−158	5.7
−200	2.1

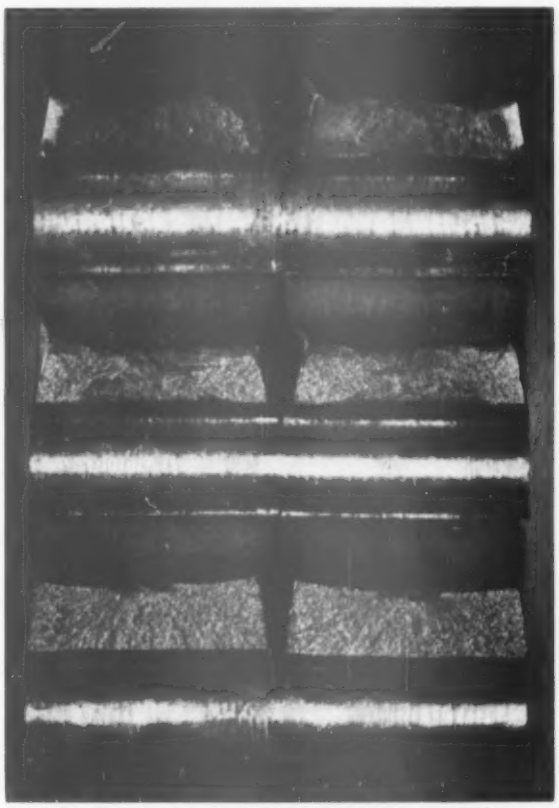

Fig. 25. Typical fractures for Schnadt-type samples containing notches with root radii of 0.125 in. Steel A212 with a maximum temperature of 1700° F. Testing temperatures and lateral contractions at failure are indicated. 4.0 ×

T_t, °F	L.C., %
− 47	19.3
− 82	18.0
−200	13.0

4. A region of spheroidization marking the outer boundary of the visible heat-affected zone where the peak temperature causes coalescence of the carbides into spheroidal particles. Within this region, the only visible change is in the distribution of the carbides since austenitization does not occur. The peak temperatures associated with this region are found just below the effective value of the A_{c1} for the steel.

5. A region generally described as the strain-aged region where the peak temperature attained is appreciably below the critical temperature range for the steel. Within this region, no visible change in microstructure may be detected, although marked changes in mechanical properties have been demonstrated for some steels. Other investigators have shown that peak temperatures within this region have particularly deleterious effects on some steels.[17]

For the purposes of the present investigation, it was decided to subject the three steels listed in Table 5 to heat treatment designed to duplicate the structures found within the last four regions described above. Using arc-weld thermal-cycle data published by Nippes, *et al.*[28], suitable thermal cycles for duplicating these structures were calculated. The resulting thermal cycles are shown in Fig. 27, and the significant details of each thermal cycle studied are shown in Table 7.

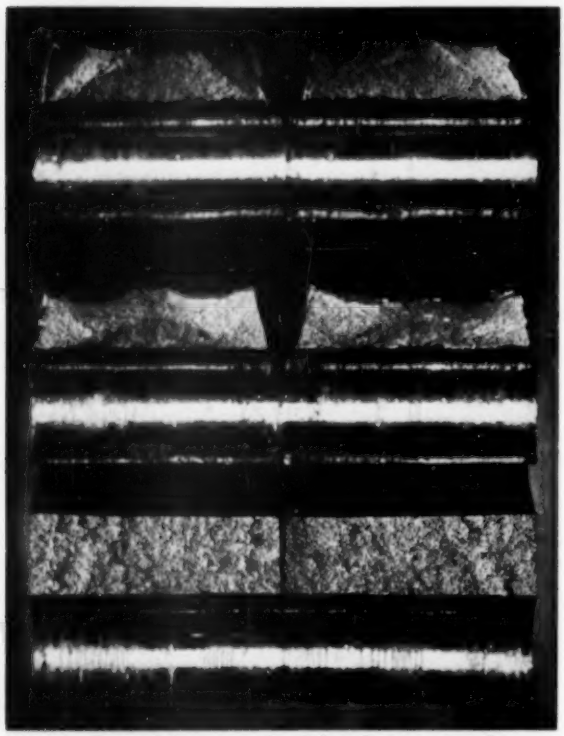

Fig. 26 Typical fractures for Schnadt-type samples containing notches with root radii of 0.250 in. Steel A212 with a maximum temperature of 1700° F. Testing temperatures and lateral contractions at failure are indicated. 4.0 ×

T., ° F	L.C., %
−102	20.0
−180	16.1
−320	2.3

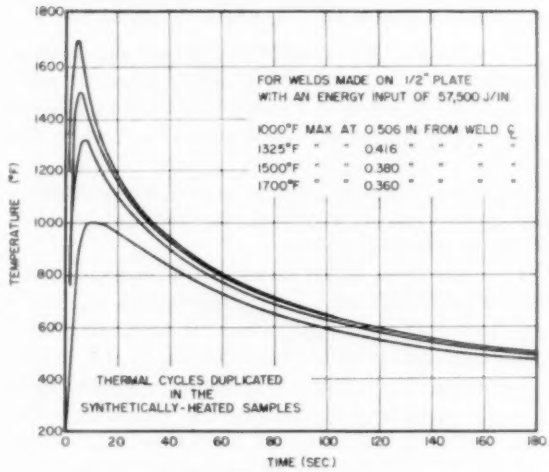

Figure 27

Table 7—Summary of Thermal Cycles Studied

In each case, thermal cycles are those found at indicated distances from weld centerline of welds made in 1/2-in. plate with an energy input of 57,500 j/in. and an initial plate temperature of 72° F

Peak temperature, ° F	*Time to reach peak temperature, sec.*	*Structure produced*
1700	5	Totally refined microstructure found at 0.36 in. from weld centerline
1500	5.75	Partially refined microstructure found at 0.38 in. from weld centerline
1325	7.2	Spheroidized structure found at 0.42 in. from weld centerline*
1000	10.6	"Strain-aged" material found at 0.51 in. from weld centerline

* Whereas this thermal cycle was chosen to produce a spheroidized structure, through a curious anomaly, a trace of austenitization was subsequently found to result in two of the steels. This would indicate that a slightly lower peak temperature should have been utilized to obtain a true spheroidized structure.

Since large grain size has a pronounced tendency to embrittle a steel it would be expected that peak temperatures higher than those studied here would produce a progressively more brittle material.

It should be noted that with the high-speed time-temperature control device used for duplicating the desired thermal cycles, the rigid mounting of the samples caused a strain of thermal expansion and contraction during heat treatment. The action of these strains during synthetic heat treatment simulates the action of strains on the heat-affected zones during actual welding.

EFFECT OF THERMAL CYCLES ON THE MICROSTRUCTURE

Figure 28 illustrates, at 500×, the microstructures produced in the three steels by the selected thermal

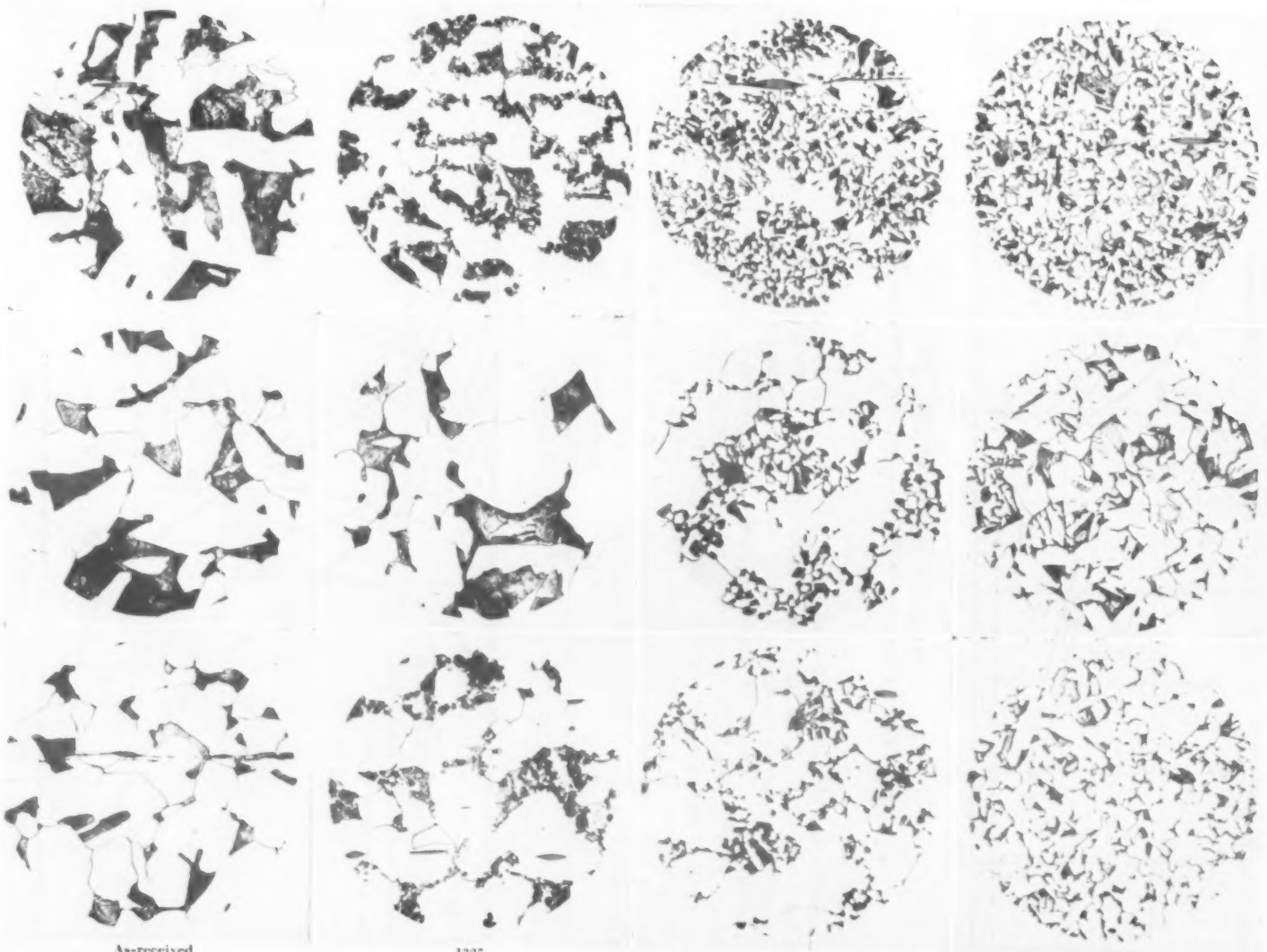

Fig. 28 Microstructures developed in Schnadt samples by the indicated thermal cycle associated in welding. 57,500 j in. 1/2-in. plate. 2% Nital etch. 350 ×

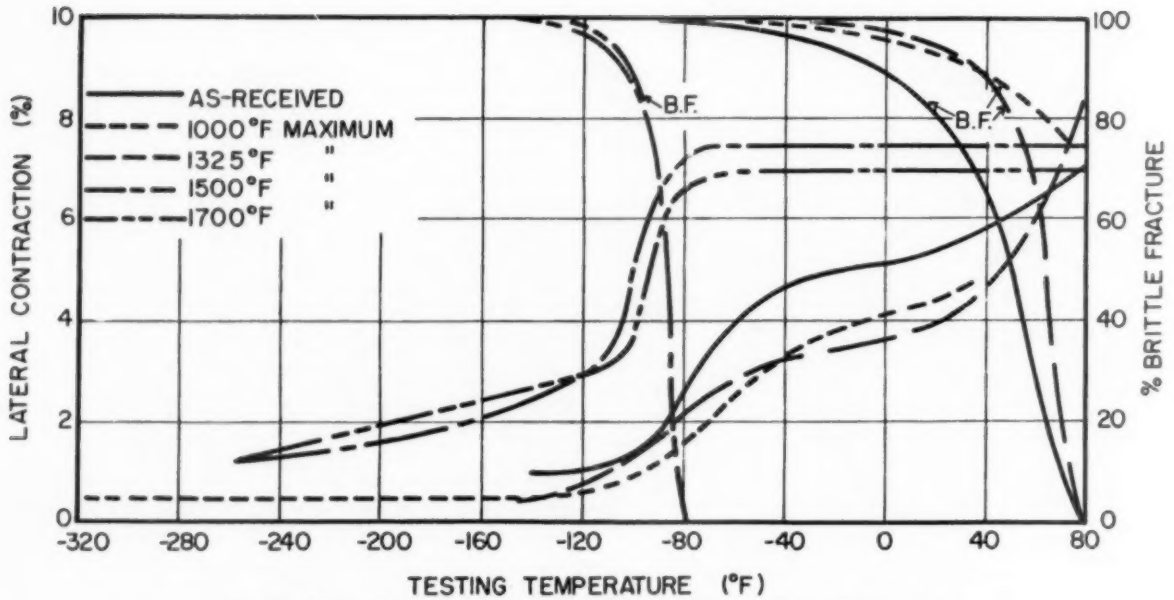

Fig. 29 Effect of thermal cycles on ductility, Steel A212, Schnadt-type test

cycles. Included are photomicrographs at 500× of each of the three steels in the as-received condition in order that changes in microstructure may be readily detected by comparison. It should be noted that although the A201 steel had a lower carbon content than the A285 steel, the A201 exhibits a greater proportion of pearlite in its microstructure. This phenomenon is taken as evidence of differing finishing practice for these two steels. As would be expected however, the A212 steel, having the highest carbon content of the three, exhibits the greatest proportion of pearlite in its microstructure.

The thermal cycle having a peak temperature of 1000° F produced no visible change in the microstructure in any of the four steels. The 1325° F thermal cycles caused partial refinement of the A212 and A285 material but did not heat the A201 samples above their critical temperature. Some evidence of spheroidization was seen but it is not understood why the A201 grade with a negligible difference in its composition, as compared to the A285, exhibited a different critical temperature.

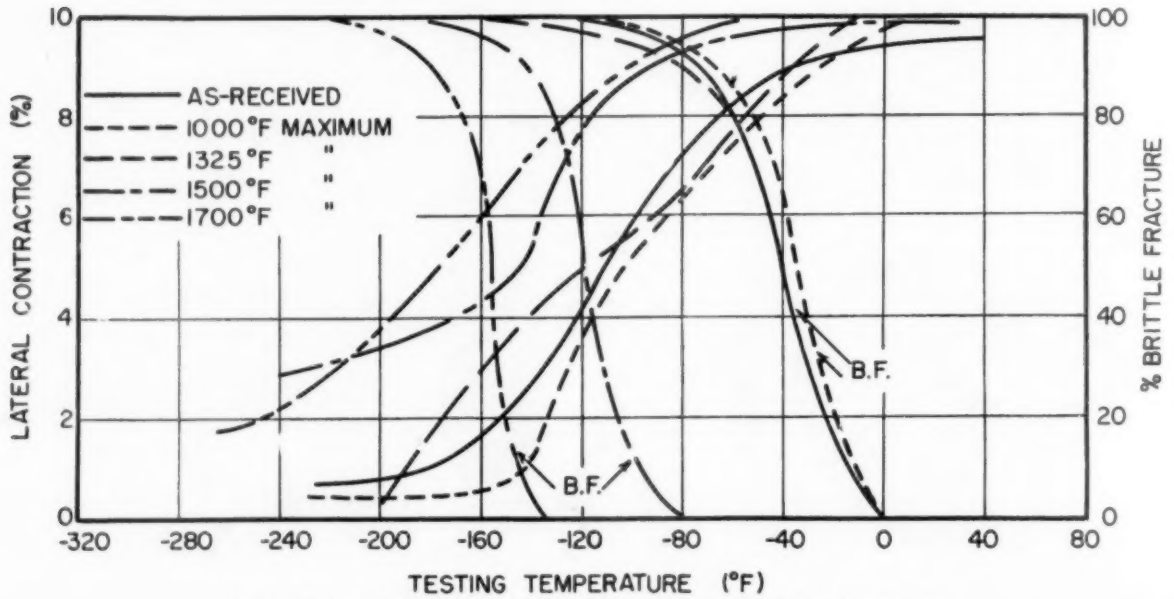

Fig. 30 Effect of thermal cycles on ductility, Steel A201, Schnadt-type test

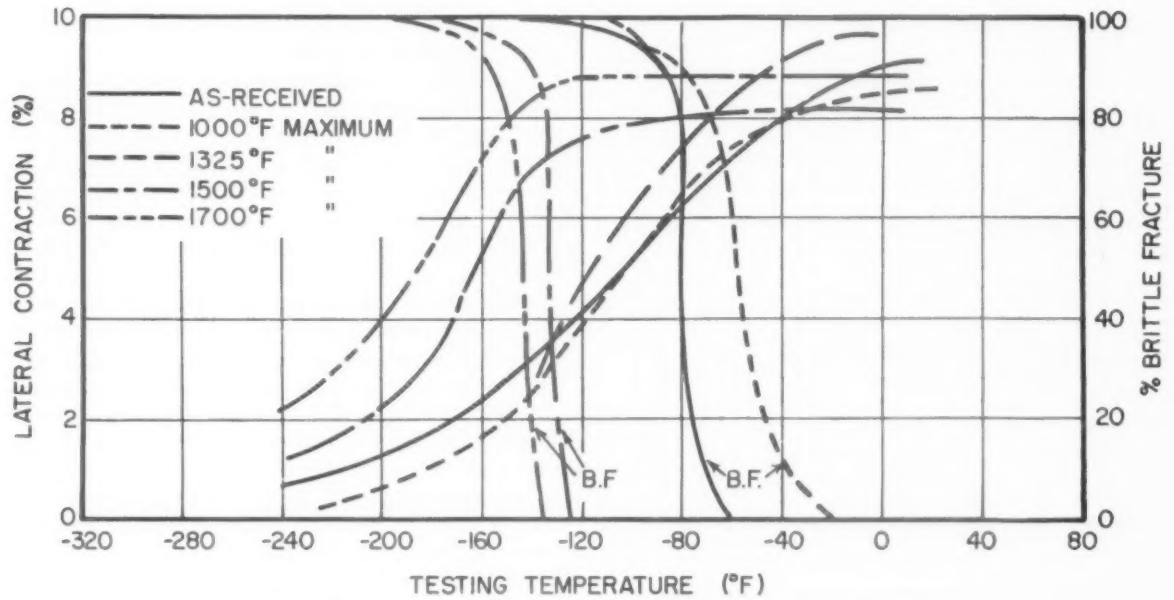

Fig. 31 Effect of thermal cycles on ductility, Steel A285, Schnadt-type test

The 1500° F peak-temperature thermal cycle produced a partially refined structure in all of the mild steels. The thermal cycle having a 1700° F peak temperature caused complete refinement of all structures. The marked difference in grain size of the refined structure and the prime structure should be noted.

EFFECTS OF THERMAL CYCLES OF WELDING

Curves of lateral contraction as a function of testing temperature were plotted from the Schnadt-sample data in a manner similar to that previously described in Part I for the Kinzel test. Additional curves of the fracture appearance, expressed as percent brittle fracture, were also plotted as a function of the testing temperature.

The composite curves of lateral contraction and brittle fracture as a function of testing temperature for the stress concentration factor of 5 are given in Figs. 29 to 31. It was decided to adopt the fracture transition temperature at the point of 50% brittle fracture since the curves dropped sharply in this vicinity. The criterion of 3% lateral contraction was adopted as the ductility transition criterion since this contraction could be located on all curves and because at this criterion with a stress concentration factor of 5, the samples were approximately 99% brittle. A summary of the ductility transition temperatures obtained in this phase of the investigation is given in Fig. 32. The ductility, fracture and energy transitions are given in Tables 8 to 10.

The above tables show a definite superiority of the 1500 and 1700° F maximum temperature thermal cycles. This increased ductility, indicated by lower transition temperatures, is attributed to the smaller

Table 8—Ductility Transition Temperatures in ° F

Schnadt-Type Specimen with Charpy V-Notch
3% Lateral Contraction Criterion

*Condition, ° F**	*A212*	*A201*	*A285*
As-received	−75	−140	−145
1000	−50	−125	−135
1325	−50	−160	−135
1500	−120	−220	−185
1700	−120	−220	−220

* The temperatures refer to the peak temperature experienced during the thermal cycle used to produce the microstructure. See Table 7 for additional data.

Table 9—Fracture Transition Temperatures in ° F

Schnadt-Type Specimen with Charpy V-Notch
50% Brittle Fracture Criterion

Condition, ° F	*A212*	*A201*	*A285*
As-received	50	−40	−80
1000	80	−35	−60
1325	65	−40	−80
1500	−85	−120	−130
1700	−85	−155	−145

Table 10—Energy Transition Temperatures in ° F

Schnadt-Type Specimen with Charpy V-Notch
10 Ft-Lb Criterion

Condition, ° F	*A212*	*A201*	*A285*
As-received	−45	−110	−130
1000	−30	−115	−110
1325	−20	−140	−120
1500	−160	−220	−170
1700	−135	−220	−210

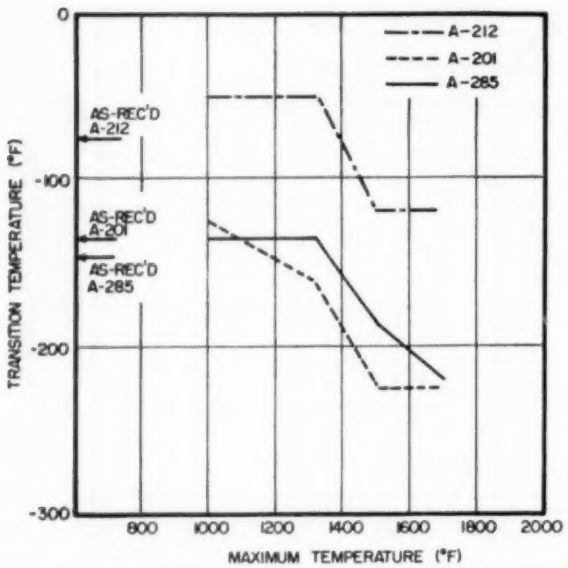

Fig. 32 Effect of maximum temperature on ductility (3% lateral contraction criterion) Schnadt-type test

grain size produced by the partially refined and refined treatments. A trend for embrittlement is shown for the subcritical heat treatments, and is most likely the result of strain aging.

It is to be recalled that the thermal cycles used in preparing these specimens simulated a weld energy input of 57,500 j/in. on $^1/_2$-in. plate. With these conditions, the cooling rates involved in the thermal cycles were comparatively slow. With lower energy inputs and faster cooling rates, the specimens exhibiting partial refinement would probably have shown a loss in ductility as evidenced by higher transition temperatures.[4] As explained previously, in these partially transformed specimens, the high carbon content of the regions transformed to austenite produces a localized increase in hardenability. These areas of high hardenability will transform to less ductile metallographic products when subjected to more rapid cooling rates.

EFFECT OF STRESS CONCENTRATION

Using the A212 steel, the ductility transition temperature data obtained by varying the notch dimensions showed little significance for two reasons.

1. The restricted volume of particular microstructure: As was previously reported, the time-temperature control device is capable of reproducing any particular thermal cycle with considerable accuracy through a limited rectangular volume of the test specimen. This section extends over the complete transverse cross section only within a volume extending for approximately $^1/_4$ in. in the longitudinal direction. Therefore, testing conditions resulting in large amounts of plastic flow, such as are associated with large-radius notches, did not yield representative test results. This situation develops whenever the distortion and plastic deformation involved in the testing extends outside the above-mentioned, restricted volume.

2. Difficulty in producing very low testing temperatures: Decreasing the stress concentration factor (increasing the radius of the notch) lowers the transition temperature markedly. In some cases, transition temperatures were lowered to the region between −240° F and the temperature of liquid nitrogen. The use of Freon 13 in the place of pentane would have resolved this difficulty, but with the scatter produced above −240° F it was felt that the resulting data would not have warranted the expense of purchasing the necessary handling equipment. It should be stated, however, that, at the temperature of liquid nitrogen, all steels studied showed a completely brittle fracture with less than 1% lateral contraction regardless of the notch geometry. It should be noted that the greater deformation experienced by samples having notches with low stress concentration factors tends to mask the properties of the desired structure due to the change in properties with plastic strain.

Using only those samples which fractured at the center of the region to be studied, the fracture transition temperatures were determined for some structures, although the limits of accuracy are not known. The fracture transition temperatures for stress concentration factors of 1.5, 2 and 5 are shown in Table 11 for the five conditions studied.

Table 11—Fracture Transition Temperatures in ° F

Schnadt-Type Test, Steel A212
50% Brittle Fracture Criterion

Condition, ° *F*	—*Stress concentration factor*— 5	2	1.5
As-received	50	−20	−90
1000	80	−10	−100
1325	65	−20	−60
1500	−85	−100	−140
1700	−85	−95	−150

Although no mathematical relationship can be established from these data, it is obvious that the fracture transition temperature decreases with a lowering of the stress concentration factor. No definite conclusions as to the notch sensitivity of the microstructures studied can be obtained from these data, although it appears that the microstructures produced by thermal cycles with 1500 and 1700° F peak temperature are less notch sensitive than the other regions studied. In addition, the regions just outside the normally considered heat-affected zone, which experienced a peak temperature of 1000° F, are the most notch sensitive of the regions studied.

CONCLUSIONS

The conclusions for this investigation are presented in two parts.

Part I. The Effects of Welding Techniques and Electrodes. This portion of the investigation utilized

the Kinzel test to determine the effect of E6010 and E6016 type electrodes on the ductility of three plain carbon 1-in. steels. These steels were silicon killed and contained 0.25, 0.19, 0.16% carbon, respectively. Included in this study were the effects of 400° F preheat, 400° F postheat, a combination of 400° F preheat and postheat, 1150° F stress-relief heat treatment, and the effect of weld energy input. The more important results of this part of the investigation were as follows:

1. With energy inputs of 55,000 j/in., the transition temperatures of the steels, as determined by the lateral contraction criterion, were increased 150 to 190° F for both electrode types.

2. In the as-welded condition, the E6016 electrode was superior to the E6010 only with the steel containing 0.25% carbon, the highest of the three carbon contents investigated. In this case, the transition temperatures differed by 40° F.

3. For all other conditions investigated in these three steels, there was no difference in the transition temperature between E6010 and E6016 electrodes.

4. Using a 1% lateral contraction criterion for transition temperature, the effect of 400° F preheat was to lower the as-welded transition temperature approximately 40° F for both the E6010 and E6016 electrodes with the two steels of lower carbon content. For the steel of highest carbon content, the effect of 400° F preheat was to lower the transition temperature approximately 80° F for the E6010 electrode and 40° F for the E6016 electrode.

5. The effect of a 24-hr postheat at 400° F in improving the as-welded transition temperature was approximately equivalent to that of a 400° F preheat for both electrode types with all three steels.

6. For a combination of 400° F preheat and 400° F postheat, the as-welded transition temperature was lowered approximately 85° F for both electrode types with the two steels of lower carbon content. For the 0.25% carbon steel, the effect of this combination treatment was to lower the transition temperature approximately 85° F for the E6010 electrode and 45° F for the E6016 electrode.

7. A 1-hr stress-relief heat treatment at 1150° F lowered the as-welded transition temperature approximately 110 to 140° F. These temperatures are within 40 to 50° F of the transition temperature of the as-received plate material.

8. The change from medium to high values of energy input had little effect on the transition temperature of the 0.25% carbon steel welded with E6016 electrodes without preheat.

9. With 400° F preheat, the change from medium to low values of energy input had little effect on the transition temperature of the 0.25% carbon steel welded with E6016 electrodes.

10. Although the transition temperature of the 0.16% carbon steel was raised by prestraining and aging, prestrained and welded specimens had a lower transition temperature than the as-welded specimens.

Part II. The Effects of Thermal Cycles of Welding. This portion of the investigation utilized a Schnadt-type sample to determine the effect of weld thermal cycles on the ductility of three plain-carbon silicon-killed steels. These samples were synthetically heat treated by means of a high-speed time-temperature controller which duplicated the thermal cycles present in heat-affected zones. The results of this preliminary investigation were as follows:

1. For the thermal cycles investigated, the brittle-fracture criterion for determining transition temperatures resulted in a sharper transition change than either the lateral contraction or energy absorption criterion. Furthermore, when comparing different microstructures, the brittle fracture criterion gave the greatest difference in transition temperatures.

2. Under the conditions investigated the regions outside of the normally considered heat-affected zone had the highest transition temperatures.

3. For moderate energy inputs the partially refined regions of the weld heat-affected zones had transition temperatures approximately equivalent to those of the as-received materials.

4. Under these same conditions, the refined regions of the heat-affected zones had transition temperatures considerably lower than those of the as-received materials.

5. The notch sensitivity of various heat-affected regions was determined from the rise in transition temperature which resulted when the stress-concentration factor of the notch was increased. The refined regions were found to be the least notch sensitive; the regions just outside the normally considered heat-affected zone were the most notch sensitive.

ACKNOWLEDGMENTS

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References

1. Hollomon, J. H., and Zener, C., "Conditions of Fracture of Steel," *Trans. AIME*, **158**, 283–297 (1944).
2. Hollomon, J. H., "The Notched-Bar Impact Test," *Ibid.*, **158**, 298–322 (1944).
3. Grossman, H., and Shepler, P. R., "The Effect of Welding Technique on Brittle Transition Temperature," THE WELDING JOURNAL, **26**, Research Suppl., 321-s to 331-s (1947).
4. Stout, R. D., McGeady, L. J., Sun, C. P., Libsch, J. F., and Dean, G. E., "Effect of Welding on Ductility and Notch Sensitivity of Some Ship Steel," *Ibid.*, **26**, Research Suppl., 335-s to 357-s (1947).
5. Kinzel, A. B., "Ductility of Steels for Welded Structures," *Trans. ASM*, **40**, 22–81 (1948).

6. Stout, R. D., and McGeady, L. J., "The Meaning and Measurement of Transition Temperature," The Welding Journal, **27**, Research Suppl., 299-s to 302-s (1948).
7. Rieppel, P. J., Kline, R. G., and Voldrich, C. B., "Evaluation of Tests for Steels for Welded Structures," *Ibid.*, **29** (5), Research Suppl., 195-s (1950).
8. McGeady, L. J., and Stout, R. D., "Notch Sensitivity of Welded Steel Plates," *Ibid.*, **29** (5), Research Suppl., 243-s to 251-s (1950).
9. Hess, W. F., Merrill, L. L., Nippes, E. F., and Bunk, A. P., "The Measurement of Cooling Rates Associated to the Selection of Optimum Welding Conditions," *Ibid.*, **22**, Research Suppl., 277-s to 422-s (1943).
10. Vanderbeck, R. W., "Evaluating Carbon Plate Steels by the Keyhole Charpy Impact Test," *Ibid.*, **30** (1), Research Suppl., 39-s to 64-s (1951).
11. Rinebolt, J. A., and Harris, W. J., Jr., "Effect of Alloying Elements on Notch Toughness of Pearlitic Steels," *Trans. ASM*, **43**, 1175–1201 (1951).
12. Hodge, J. M., Manning, H. D., and Reichold, H. M., "The Effect of Ferrite Grain Size on Notch Toughness," *Jnl. Metals*, **1** (3), 233–240 (1949).
13. Thielsch, Helmut, "Strain Aging of Pressure Vessel Steels," The Welding Journal, **30** (6), Research Suppl., 283-s to 290-s (1951).
14. Schaeffler, A. L., Campbell, H. C., and Thielsch, H., "Hydrogen in Mild-Steel Weld Metal," *Ibid.*, **31** (6), Research Suppl., 283-s to 309-s (1952).
15. Swan, D., Lytle, A. R., McKinsey, C. R., "Stress Relieving and Fracture Strength," *Ibid.*, **30** (3), Research Suppl., 135-s to 145-s (1951).
16. Klinger, L. J., and Evert, L. J., "Distribution of Relative Ductility in Steel Weldments," *Ibid.*, **29** (2), Research Suppl., 59-s to 73-s (1950).
17. Nippes, E. F., and Savage, W. F., "Tests of Specimens Simulating Weld Heat-Affected Zones," *Ibid.*, **28** (11), Research Suppl., 534-s to 54-s (1949).
18. Cubitt-Smith, Guy, "Further Tests of Specimens Simulating Weld Heat Affected Zones," Master's Thesis, June 1952, Rensselaer Polytechnic Institute.
19. Bruckner, W. H., and Landberg, S. W., "Strain Aging in Welded Structural Steel," *Ibid.*, **28** (9), Research Suppl., 397-s to 404-s (1949).
20. Flanigan, A. E., Bocarsky, S. I., and McGuire, G. B., "Effect of Low-Temperature Cooling Rate on the Ductility of Arc Welds in Mild Steel," The Welding Journal, **29**, Research Suppl., 459-s to 466-s (1950).
21. Fountain, R. W., and Stout, R. D., "Relative Strain-Aging Tendency of Weld and Base Metal," *Ibid.*, **30** (1), Research Suppl., 43-s to 46-s (1951).
22. Flanigan, A. E., Kaufman, M., and Emery, E. M., "Strain-Aging of Arc Welds in Mild Steel," *Ibid.*, **29**, Research Suppl., 146-s to 160-s (1950).
23. Christoffel, R. J., "Relative Effect of Composition and Microstructure on Strain Aging of Mild Steel," Bachelor's Thesis, June 1951, Rensselaer Polytechnic Institute.
24. Herres, S. A., "Practical Importance of Hydrogen in Metal-Arc Welding of Steel," *Trans. ASM* **39**, 162–188 (1947).
25. Week, R., "An Account of M. Henri M. Schnadt's Ideas on the Strength of Materials, and His Testing Methods," *Trans. Inst. Welding*, **13** (2), 41–56 (1950).
26. Palm, J. H., "The Theoretical Background and Interpretation of the Schnadt Impact Test," *Welding Research Council Bulletin*, **VI** (6), 17–35 (1951). (Translation.)
27. Aborn, Robert H., "Metallurgical Changes at Welded Joints and Weldability of Steels," The Welding Journal, **19** (10), Research Suppl., 414-s to 426-s (1940).
28. Nippes, E. F., Merrill, L. L., and Savage, W. F., "Cooling Rates in Arc Welds in 1/2-In. Plate," *Ibid.*, **28**, Research Suppl., 556-s to 564-s (1949).
29. DeGarmo, E. P., "Should Preheat Be Substituted for High-Temperature Stress Relief in the Codes," The Welding Journal, **31**, Research Suppl., 393-s to 396-s (1952).

A Qualitative Study of Residual Stresses in Welds by Photoelasticity

High peaks at center and ends of a weld may be reduced by reducing the temperature gradient in the vicinity of the weld such as by preheating

by Melvin Mark, Sc.D.

Abstract

The residual stresses present in a longitudinal butt weld were investigated by simulating welds in bakelite and applying the photoelastic method. This relatively new approach was used to determine the frozen stresses present in the transparent models representing the welded structures. The analogy between these frozen stresses in photoelasticity and residual stresses in welds showed that the largest residual stresses in a welded section occurred in the weld itself, in particular at the center and ends of the weld. Tests indicated that reducing the temperature gradient in the vicinity of the weld would materially decrease the high stress at the center of the weld and reduce the stress occurring at the ends, resulting in a better welded joint.

INTRODUCTION

THE distribution of stresses in welded structures is of considerable interest to design engineers. Experimental procedures are often useful in bringing out facts concerning stress distribution which are not easily determined by the mathematical methods of elasticity. Photoelasticity, one of these useful experimental procedures, relates the change in optical properties of certain materials to their state of stress.[1]

It is known that the physical properties of certain steels are influenced by their rate of cooling from the molten state. For a high cooling rate, the yield point, hardness and ultimate strength increase while the ductility is reduced. In welding, the metal is subjected to heating and subsequent cooling. Thermal stresses set up by the large temperature differences near a weld may produce large plastic deformations and result in residual stresses. The residual stresses together with any change in properties of the material due to rapid cooling represent a possible hazardous condition.[2]

Many problems in welding have been uncovered from time to time, and explanations of the phenomena of failure often involve residual stresses. A brief study of residual stresses by photoelasticity is discussed qualitatively here together with a procedure for relieving these stresses.

Heating the area surrounding a weld during a welding operation has been practiced. This appears to be effective in reducing the high residual stresses otherwise present and is also a means by which welding can be better carried out in cold surroundings. This paper presents pictorial evidence of the effect on residual

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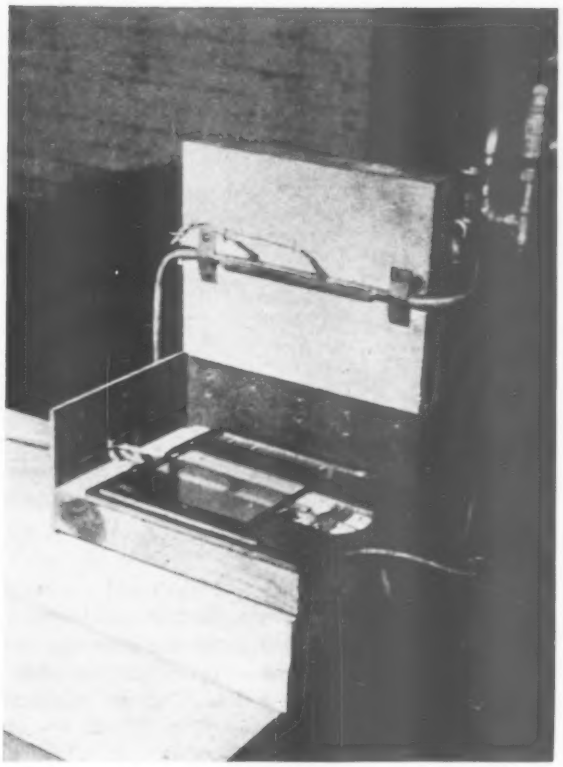

Fig. 1 Apparatus for specimen 1

stresses of reducing the temperature difference in the vicinity of the weld by local heating in this area.

EXPERIMENTAL WORK

A relatively new experimental procedure by which residual stresses in a weld were investigated involved simulating a weld in a photoelastic material and analyzing it by means of the photoelastic method. The fundamental phenomenon of fixed or frozen stress patterns is of special significance in photoelasticity. When a model is slowly cooled from the annealing temperature, any stresses acting on it throughout the period of annealing are found to be fixed in the specimen after it has reached room temperature. These fixed stresses are spoken of as frozen stress patterns, and they correspond to the residual stresses found in welding. Ryan[3] used this analogy to study residual stresses in plug welds. The author applied it to the study of a butt weld, as described in this paper.*

Photoelastic bakelite[1] was the material used in this investigation. The distribution of the frozen or residual stresses in this material can be seen by viewing the bakelite specimen in a polariscope using polarized light. The stress pattern viewed in the polariscope shows dark and bright bands in monochromatic light. The bands, or "fringes," are used to evaluate the difference in principal stresses.

Two pieces of bakelite will not fuse together. Therefore, to simulate a longitudinal butt weld, a strip heater was applied along the center line on each side of an unrestrained bakelite plate, annealing the material between the two heaters (see Fig. 1). The plate was slowly withdrawn from between the strip heaters, allowing the annealed material to set or freeze progressively. The bakelite then contained residual stresses as in welding.

Fig. 2 Apparatus for specimen 2

The strip heaters were constructed by soldering copper strips 6 x $^1/_4$ x $^1/_8$ in. to copper tubing. Controlling the steam pressure in the copper tubing, the strip could be maintained at 230° F, the temperature used for annealing the bakelite. Thermocouples in the strips measured the temperature. A special paddle supported the 8 x 6 x $^1/_4$ in. bakelite specimen and allowed it to be withdrawn from between the strip heaters and paddle. (See Fig. 1 where the apparatus is shown with the upper half disassembled.) Slow, progressive freezing of the weld necessitated about 30 min. for extracting the bakelite specimen from the assembly. A line ran from the paddle to an electric motor and allowed the paddle to be withdrawn at a slow steady speed. The bakelite plate was moved out from between the stationary strip heaters, thus forming the first specimen.

A second specimen was produced in the same manner but with the addition that heat was applied to the sections on each side and adjacent to the simulated weld, reducing the temperature difference which was present in the weld area when the first specimen was made. This was accomplished by quarter-circle metal plates attached at one end of each strip heater (see Fig. 2) and separated from the bakelite by an air gap which decreased toward the weld. The result was a linear temperature distribution in the plates which measured 178° F at the plate sections adjacent to the strip heaters and 140° F at the outer edge of the plates (approximately 2 in. from the weld). The specimen was then withdrawn slowly as before; however, the material adjacent to the weld passed between the heated plates. The frozen stresses could then be viewed in the polariscope and compared with those of the first specimen, giving some idea of the effect of the tempering treatment.

The picture of the fringe pattern for the first test specimen is shown in Fig. 3, for the second in Fig. 4. The number of fringes which appear on these photo-

* This work was carried out by the author at the University of Minnesota.

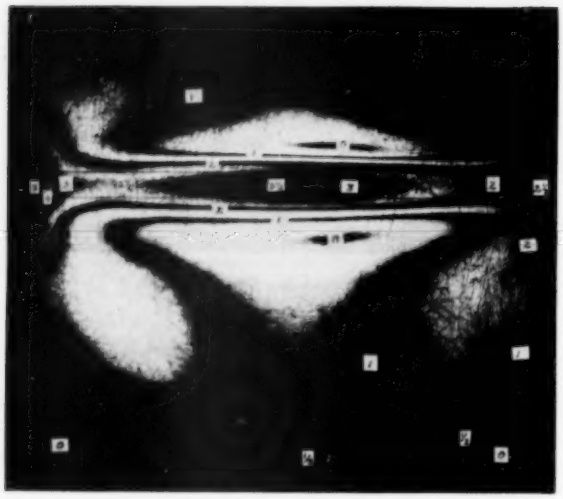

Fig. 3 Stress pattern of specimen 1

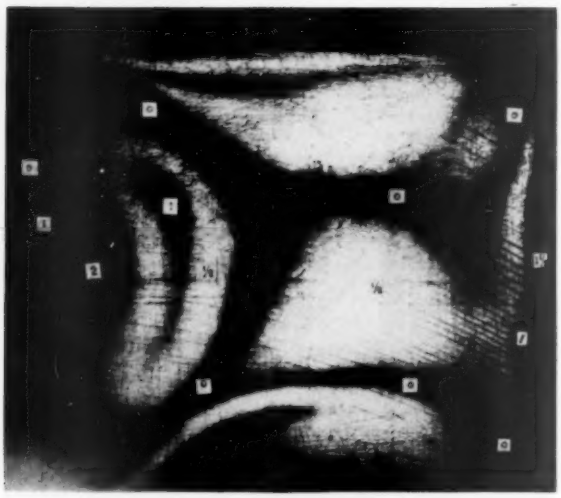

Fig. 4 Stress pattern of specimen 2

graphs is an indication of the magnitude of the difference in principal stresses.

ANALYSIS AND DISCUSSION OF RESULTS

A nonuniform temperature distribution in a body may develop high thermal stresses. If these stresses exceed the yield point, the plastic deformation which occurs will remain when the temperature distribution again becomes uniform. In this manner residual stresses are produced in welds, since the residual plastic deformations by themselves do not satisfy the compatibility conditions of elasticity.[4]

In a butt weld connecting two plates, there is a large temperature difference across the weld area, and thermal stresses are produced. A solution exists for the temperature stresses in a thin rectangular plate heated along a centerline (representing the case of two plates welded together along one side).[5] The stress can be expressed in terms of $\alpha E T_0$, where α is the coefficient of linear thermal expansion, E is the modulus of elasticity and T_0 is the temperature difference between the highest and average temperatures in the structure. The maximum stresses was found to be

$$\sigma_{max} = 1.04\ \alpha E T_0 \qquad (1)$$

occurring at what would be the ends of the weld. Equation 1 applies for the condition where the temperature difference T_0 occurs over a short distance with respect to the length of the weld (ratios of the distance over which T_0 occurs to the length of weld should be less than 1/8.)[5] In this case the maximum stress is determined solely by the maximum temperature difference and not by the temperature gradient.

T_0 characterizes the temperature difference, and if this quantity is large enough, the stress can easily exceed the yield point and plastic deformations occur. The deformations will not disappear when the temperature of the piece returns to its initial value, and residual stresses result.

The stress patterns, shown in Figs. 3 and 4, can be used to evaluate the difference in principal stresses. The difference in principal stresses, characterizing the maximum shear, is important in ductile materials. The maximum shear, τ_{max}, is related to the principal stresses, σ_1 and σ_2, by

$$\tau_{max} = 1/2\ (\sigma_1 - \sigma_2) \qquad (2)$$

We might conclude, therefore, that for ductile materials the determination of the fringe pattern may be sufficient since it indicates the areas where the difference in principal stress or maximum shear is the greatest.

For the specimens described here, there exists only one principal stress at the ends of the weld and it exists in a direction perpendicular to the length of the weld. The other principal stress is zero. In numbering the fringes, the fringe of zero order is placed at the points where it is known no residual stress occurs, as at the corners. Fringes are then counted consecutively from there on. With these factors in mind, the stress patterns can be analyzed.

Figure 3 applies to the first specimen, where a weld was simulated in the bakelite sheet with no attempt to reduce the maximum temperature difference present. It can be observed that there occur three points on the specimen at which the difference in principal stresses is high. At the center of the weld the fringe order is $3^1/_2$, which indicates one possible dangerous point. The other two occur at the ends of the weld. At one end (the end where the weld was begun) the fringe order is 5 while at the other it is $2^1/_2$. From this it appears the highest stress occurs at the start of the weld. This maximum stress is in compression and normal to the length of the weld. It is to be noted that the procedure used here for simulating the weld in bakelite differs somewhat from welding practice in that an actual weld is progressively heated as well as cooled. This may account for the stress at one end of the weld being higher than that at the other end in the bakelite model.

Figure 4 applies to the second specimen where the

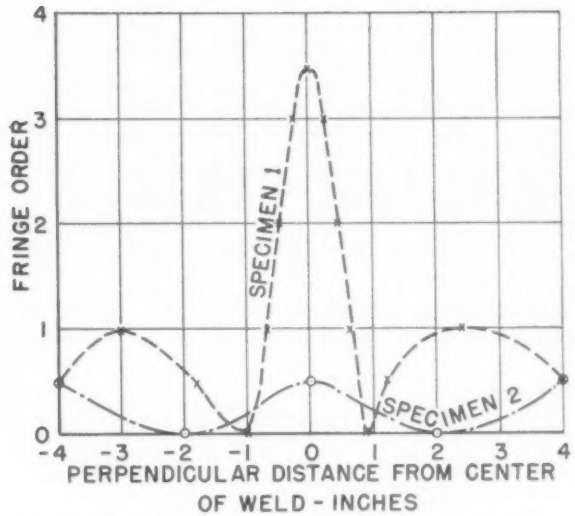

Fig. 5 Stress distribution normal to weld through center of weld

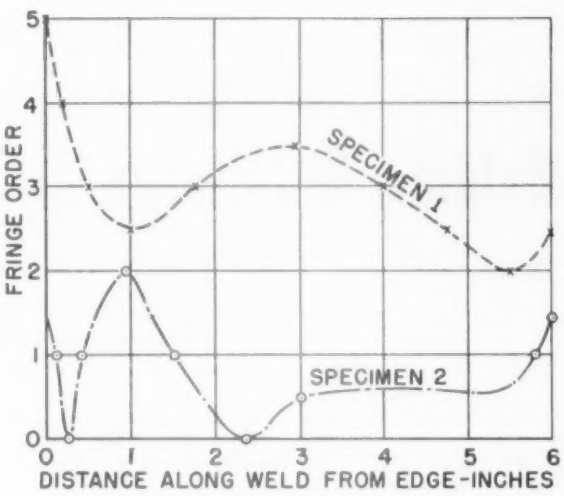

Fig. 6 Stress distribution in weld

temperature difference occurring over a given distance adjacent to the weld was reduced by means of heated metal plates. The residual stresses in the weld were certainly reduced, but new stress bands appeared in the region originally under the plates (left half of Fig. 4). The fringe order is 2 in this region due to the residual stresses caused by the plates being allowed to heat the region over so long a period of time. In the region of the weld that was not under the plates originally, a more favorable temperature distribution was obtained as the weld was about to cool, and it can be seen from the right half of Fig. 4 that the stresses in the central region were reduced to a fringe order of one-half. The high stresses still occur at the ends of the weld, but there the fringe order is $1^1/_2$, compared with $2^1/_2$ and 5 for the first specimen. The region of stress in center of the weld is seen to have been materially reduced. Figures 5 and 6 are graphs comparing the number of bands for the two specimens. It can be seen readily that a reduced temperature difference decreases the residual stresses characterized by the difference in principal stresses.

Photoelasticity presents a new approach to the problem of residual stresses in welds. The results of this study indicate that it may be successfully applied and give satisfactory results. Carried further, and with certain refinements, the photoelastic method may allow quantitative as well as qualitative answers in this type of work.

CONCLUSIONS

The extent to which residual stresses are present in a welded section depends upon the magnitude of the plastic deformation caused in the structure by the thermal stresses set up during welding. Photoelasticity offers a new means by which these stresses may be studied. The results of this photoelastic investigation show that these stresses (as characterized by the difference in principal stresses) may be reduced by effectively decreasing the temperature gradient over the area surrounding the weld. The analogy between frozen stresses in photoelasticity and residual stresses in welding showed that, in general, the larger residual stresses in a welded section occurred in the weld itself, in particular, at the center and ends of the weld. Properly reducing the maximum temperature difference near the weld, however, materially decreased the high stress at the center of the weld and reduced the stresses occurring at the ends.

References

1. Frocht, M., *Photoelasticity*, Vol. I, John Wiley & Sons, Inc., New York, N. Y., Chapters V and X (1941).

2. Leder, P. L. J., "Factors Influencing the Weldability of High Tensile Alloy Steels, and a New Weld Cracking Test," *Proc. Inst. Mech. Engrs. (London)*, **159**, 173–190 (1948).

3. Ryan, J. J., "Photoelastic Models Reveal Weld Stresses," *Welding Engr.*, **32**, 46–48 (February 1947).

4. Timoshenko, S., *Theory of Elasticity*, McGraw-Hill Book Co., Inc., New York, N. Y., p. 196 (1934).

5. Den Hartog, J. P., "Temperature Stresses in Flat Rectangular Plates and in Thin Cylindrical Tubes," *Jrl. Franklin Inst.*, **222** (2), 149–181 (August 1936).

Welding Metallurgy of Nodular Cast Iron

The structure of two heat-affected zones and the weld metal in nodular iron with and without preheat and postheat are described

by Edward E. Hucke and Harry Udin

Abstract

Nodular cast iron can be considered metallurgically as a low-alloy steel containing soluble spheroidal graphite inclusions. It is more difficult to join than ordinary gray irons, not so much because of inherent weldability difficulties, but chiefly because it is a superior engineering metal, and therefore requires superior joint physicals.

Even in the absence of filler metal, the weld-affected zone can contain three regions of interest. The outermost is heated above the eutectoid but below the eutectic temperature. The next is a narrow region heated to or just above the eutectic. Inside this is a region, the fusion zone proper, heated well above the eutectic. This paper deals with the structure of each of these regions when nodular iron is welded with and without preheat.

Pre- or postheat treatment did not render the fusion zone ductile. The important conclusion is that a brazing process operating below the eutectic temperature is indicated for joining nodular cast iron. It should be a fast process operated without preheat, in order to minimize the width of the region containing martensite shells, and the thickness of the shells themselves. Research toward producing a nodular structure in the fusion zone is apt to be futile, because at the necessary welding temperature the formation of a weak, brittle region in the heat-affected zone seems fundamentally unavoidable.

INTRODUCTION

DURING the past few years, nodular cast iron has achieved considerable industrial importance. A major limitation to its industrial application has been the lack of a good structural joining method.

In the foundry nodular cast iron presents certain advantages over cast steel with respect to lower melting temperature, greater fluidity and less shrinkage. As a result, nodular cast iron has a large potential use in weldment-casting fabrication.

Ordinary gray cast iron has extremely low ductility and therefore a weld can be tolerated with low ductility. However, nodular cast iron can exhibit strength and ductility comparable to cast steel. It is apparent from this fact that one criterion of a suitable joining method must be both a strong and ductile joint, at least if the properties of the base material are to be fully utilized. An equally important consideration for large-scale structural joining is low cost.

The reactions that occur in the base plate during welding heat cycles are the fundamental reasons that any cast iron presents problems in joining. The primary aim of this paper is to consider in some detail these reactions.

Nodular cast iron may be thought of as a low-alloy (Si, Ni, Mn) steel containing an amount of graphite equivalent to ordinary cast iron, but in spherulitic form. This low-alloy matrix may have numerous structures depending on previous heat treatment. Accordingly, a joining method for spherulitic cast iron will necessarily encounter all the problems met in joining low-alloy steels in addition to difficulties due to the presence of free graphite.

The major problems encountered are the formation of a hard, brittle continuous carbide region surrounding the weld, and the formation of a martensite network immediately adjacent to this carbide region.

Martensite formation is common in ferrous welding and may be partially eliminated by (1) preheating to lessen the rate of cooling through the critical range, or by (2) postheating to temper the martensite formed. Also, the deleterious effect of martensite can be minimized by choice of welding variables (increasing welding speed, decreasing arc power) in order to decrease the width of the region.

The carbide formation, however, offers a more difficult problem to solve. This carbide region is a result of rapid diffusion of carbon from the graphite nodules resulting in a lowering of the melting point of the matrix, causing fusion to start around each nodule. The liquid formed in this way corresponds roughly to liquid cast iron, which freezes as white iron due to the relatively high cooling rates encountered during welding heat cycles.

Preheating does not solve this problem, since in order to obtain a freezing and subsequent cooling rate slow enough to allow graphitization, the preheat temperature would have to approach the melting temperature. Such preheats would be commercially out of the question.

The use of a ferritizing postheat treatment is not

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Table 1—Summary of Arc Passes Made on Nodular Cast-Iron Plates Without Depositing Filler Metal

Run	*Plate composition*	*Arc current, I, amp*	*Arc voltage, V, v.*	*Arc power P_A, w*	*Speed of welding S, ipm*	*Energy, E, joules per inch of weld*	*Preheat temp., ° F*	*Postheat treatment*
1	A*	60	25	1500	10	9,000	N	N
2	A	80	25	2000	8	15,000	N	N
3	A	120	25	3000	6	30,000	N	N
4	A	80	20	1600	12	8,000	800	N
5	A	80	15	2000	8	15,000	400	N
6	A	120	25	3000	6	30,000	200	N
7	A	80	25	2000	8	15,000	N	F
8	B	60	25	1500	10	9,000	N	N
9	B	80	25	2000	8	15,000	N	N
10	B	120	25	3000	6	30,000	N	N
11	B	80	20	1600	12	8,000	800	N
12	B	80	25	2000	8	15,000	400	N
13	B	120	25	3000	6	30,000	200	N
14	B	80	25	2000	8	15,000	N	F

* Abbreviations used: A = C, 3.30%; Si, 3.50%; Ni, 1.90%; Mn, 0.24%; P, 0.025%; S, 0.015%; Ti, 0.06%; Mg, 0.084%. B = C, 3.20%; Si, 3.35%; Ni, 0.85%; Mn, 0.25%; P, 0.025%; S, 0.014%. N = None. F = 1675° F for 30 min; 1275° F for 4 hr; air cool.

NOTE: (1) All plates were $^1/_2$ x 6 x 8 in. (2) In this work, current and arc voltage were not measured, but were estimated from generator settings and arc lengths. (3) $E = 60(I)(V)/S$.

satisfactory either, since the carbide region graphitizes in very small nodules which have a deleterious effect.* Such a treatment would not be commercially feasible anyway, because it must be carried out at high temperatures (about 1675° F) for substantial times and thus must be done in a furnace. Such a treatment is not only costly, but limits the size of weldments to the practical size of furnaces capable of reaching 1675° F.

EXPERIMENTAL DESCRIPTION

A series of arc passes was made by moving a base plate under an inert-gas-shielded arc torch by means of a controllable speed carriage. Base plate composition, energy per unit length of pass, preheat temperature and postheat treatment were used as variables. Table 1 summarizes the tests made.

Table 2 summarizes a group of welds and weld passes made. All tests were done manually using the lowest arc power consistent with good welding performance. Preheat, postheat treatment, method of welding and type of filler rod were the variables.

In order to eliminate the effect of plate size, a 6- x 8 x $^1/_2$-in. plate was used which was chosen so that no point on its bottom side would increase in temperature more than 100° C during any pass.

* Unpublished work done by the International Nickel Co., Inc.

DISCUSSION OF RESULTS

The discussion of structures will be presented first with reference to arc passes, and then will be extended to weld passes. The variables studied were found to change the resulting structures only in detail, and therefore the common characteristics are treated with the specific effect of each variable noted later.

Mechanism of Melting

Considerable information results from examining the mechanism of melting of the base plate. Figure 1 can be taken as an approximate nonequilibrium diagram for the system, where the phase lines are for a rate of heating comparable to that of welding.

Consider a single nodule of graphite surrounded by a ferrite matrix undergoing rapid heating and cooling due to an arc pass. At some time after the arc has passed over this nodule, it and its surroundings will be

Table 2—Summary of Weld or Weld Passes Made on Nodular Cast Iron

Run	*Plate composition*	*Preheat, ° F*	*Postheat treatment*	*Method of welding*	*Pass or weld*	*Filler rod*
15	B*	N	N	A-C Arc	Pass	Commercial mild steel electrode
16	B	200	N	A-C Arc	Pass	Commercial mild steel electrode
17	B	Dull red	N	Oxy-acetylene	Weld	Mild steel
18	B	N	N	A-C Arc	Pass	25–20 Stainless steel
19	B	N	N	D-C Arc	Weld	3.5% Ni steel
20	B	Dull red	N	Oxy-acetylene	Weld	Phosphor bronze
21	B	N	N	Atomic hydrogen	Weld	Armco iron
22	B	N	F	A-C arc	Pass	Mild steel coated electrode
23	B	N	N	Oxy-acetylene	Braze Weld	Eutectic Welding Alloys Corp., Composition 14

* Abbreviations used: B = C, 3.20%; Si, 3.35%; Ni, 0.85%; Mn, 0.25%; P, 0.015%; S, 0.014%; Mg, 0.064%. F = 1675° F for 30 min; 1275° F for 4 hr; air cool. N = None.

NOTE: (1) All plates were in the as-cast (ferritic) condition prior to welding. (2) Arc power was kept to lowest values consistent with arc performance. (3) All welds and passes were made manually.

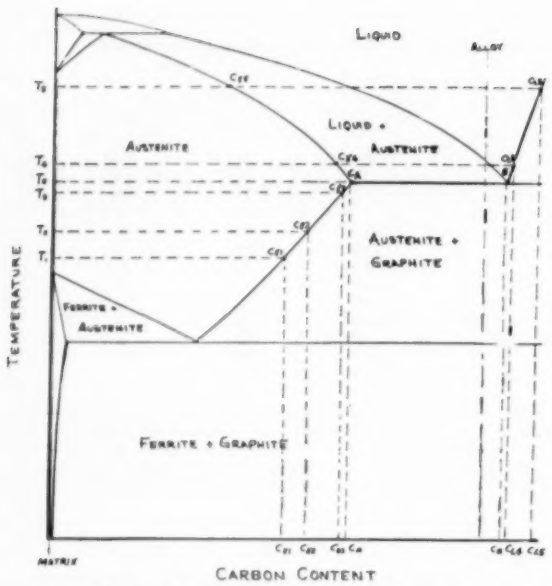


Fig. 1 A representative phase diagram

heated extremely rapidly to a peak temperature. The time required to reach peak temperature, the peak temperature and the rate of heating are determined (for a given arc power and pass speed) by the distance between the particular nodule and the line of pass on the plate surface. As this distance increases, the peak temperature and the rate of heating decrease while the time to reach peak temperature increases.

Before being heated, the area under consideration has a carbon gradient as in Fig. 2. While passing through the austenite range, the gradient may be represented by Fig. 3. The austenite at the nodule interface remains saturated while the carbon diffuses outward at

Fig. 2 Idealized carbon gradient around each nodule before heating

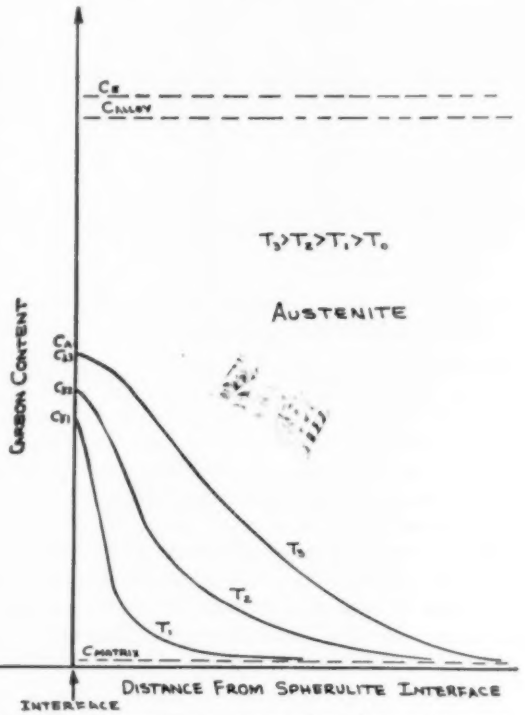


Fig. 3 Carbon gradient at times when the area is passing through the austenite range

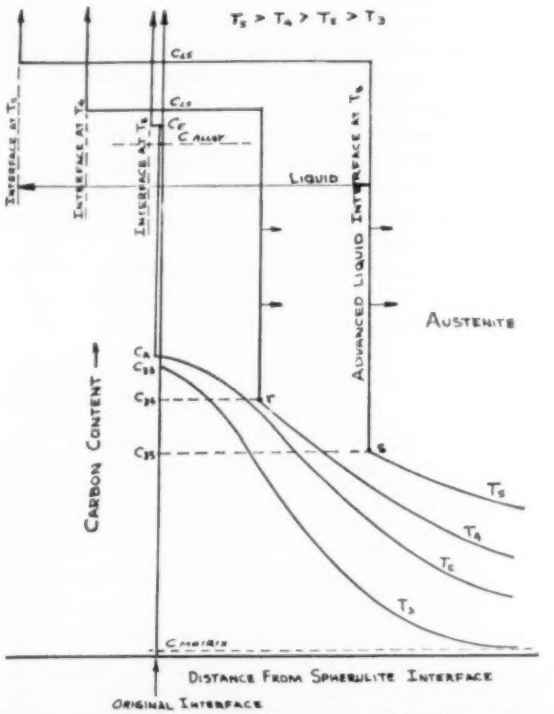
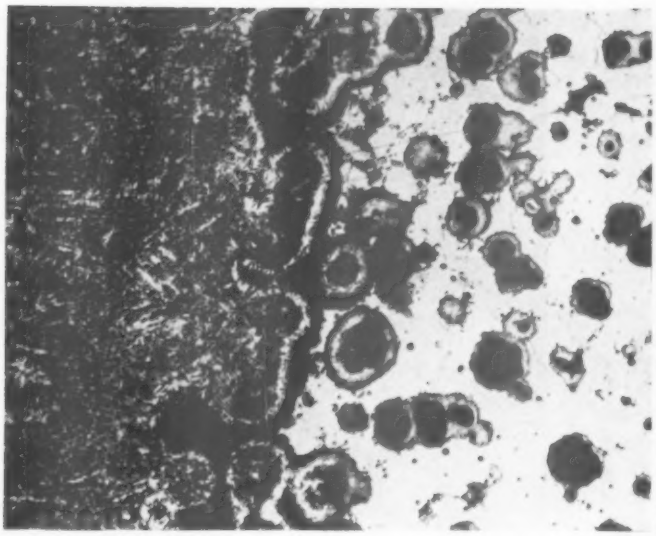
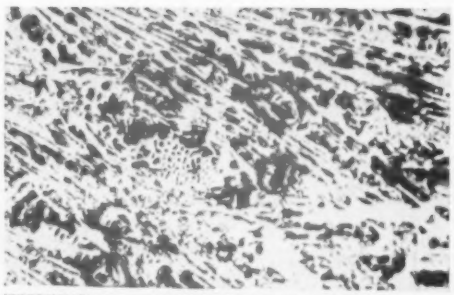


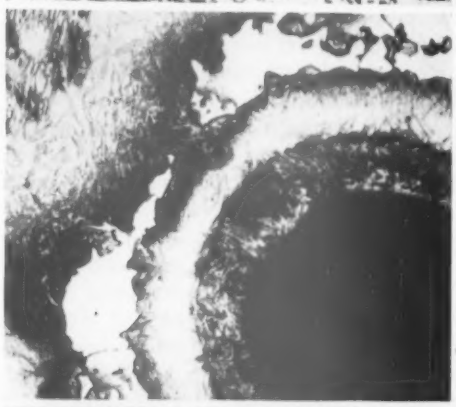
Fig. 4 Carbon gradient around each nodule after melting has started, but before complete fusion



(a)



(b)



(c)

(d)

Fig. 6 (a) Photomicrograph of a typical arc pass. Region 4 is on the left, and Region 2 is on the right. Nital etch. 100 ×

Fig. 6 (b) Photomicrograph of Region 4. Structure is carbide (white) plus eutectic. Nital etch. 500 ×

Fig. 6 (c) Photomicrograph of Region 3. Structure is nodular graphite, martensite, carbide plus eutectic, martensite grading to pearlite, and ferrite. Nital etch. 500 ×

Fig. 6 (d) Photomicrograph of Region 2. Structure is nodular graphite, martensite grading to pearlite, and ferrite. Nital etch. 500 ×

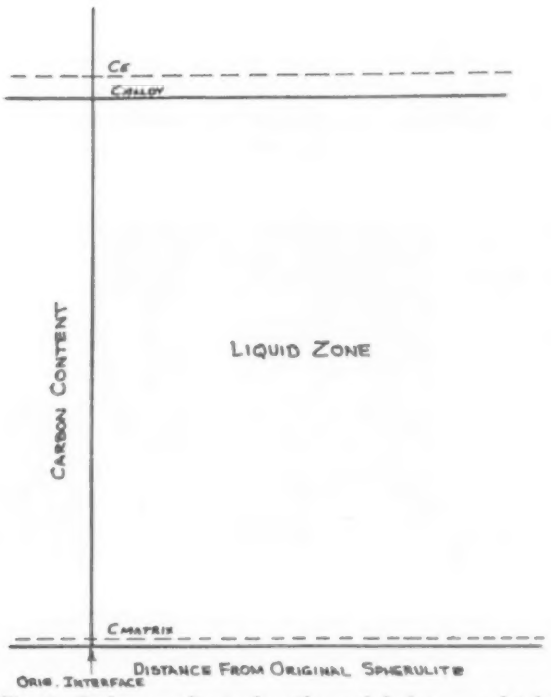


Fig. 5 Carbon gradient after the nodule has completely dissolved

an ever-increasing rate due to the increasing temperature and the rise of carbon saturation value with temperature.

When the temperature is such that the carbon content at the interface reaches point A in Fig. 1, liquid of composition E is formed. Substantially no carbon gradient occurs in this liquid due to very rapid diffusion. When the temperature reaches T_4, the carbon in the saturated liquid increases to C_{L4}, while the austenite saturation value decreases to $C_{\gamma 4}$. Therefore, the liquid interface moves out until it reaches a point r (see Fig. 4) where the carbon value has just reached $C_{\gamma 4}$ by diffusion. The nodule interface moves back a related

amount. As the temperature rises to T_s, the liquid interface moves out to point s in like fashion.

Figure 5 shows the carbon gradient at a time after the liquid interface has met those of neighboring spherulites. The carbon composition immediately approaches that of the over-all alloy due to very rapid diffusion.

Typical Structures

The foregoing mechanism of fusion can explain all the various structures found in the base plate. Figure 6 shows a typical cross section of an arc pass denoting four regions of interest.

Region 1. That portion of the base plate not affected by the arc pass has been designated as Region 1 and therefore shows a structure of nodular graphite in a ferrite matrix.

Region 2. This region represents an area whose peak temperature never reached T_E, i.e., no liquid was ever present. The carbon gradient around each nodule was therefore similar to that of Fig. 3. The structure in this region was nodular graphite surrounded by a gradation of austenite transformation products. Since the austenite had a carbon content varying from saturation to a very low value, a complete gradation of transformation products was to be expected.

Region 3. This region was defined as those areas where liquid existed around each nodule, but where the liquid interfaces from neighboring nodules had not met. Figure 4 represents the carbon gradient to be found in Region 3. It is interesting to note that some liquid penetrated along grain boundaries ahead of the main liquid interface. Figure 7 shows two liquid areas joined by a liquid network which advanced along grain boundaries. This behavior would be expected due to slightly higher carbon and other impurity content at the grain boundaries.

The high-carbon liquid surrounding each nodule in Region 3 at peak temperature solidified as primary carbide and eutectic, while the austenite surrounding this liquid transformed to martensite. The once-liquid region, corresponding roughly to ordinary white cast iron, partially ferritized on cooling, giving two slightly different structures, depending on the cooling rate and composition. With slow cooling rates and composition favoring graphitization, the carbide in a narrow ring surrounding each spherulite deposited graphite on the nodule leaving a ferrite ring. Nital and sodium-picrate etches were used to show that this ring was ferrite, as can be seen in Fig. 8. From the nodule outward, the structure in this case is: nodule, ferrite, carbide and eutectic, martensite, and pearlite extending to the original ferrite (see Fig. 8 (*c*)).

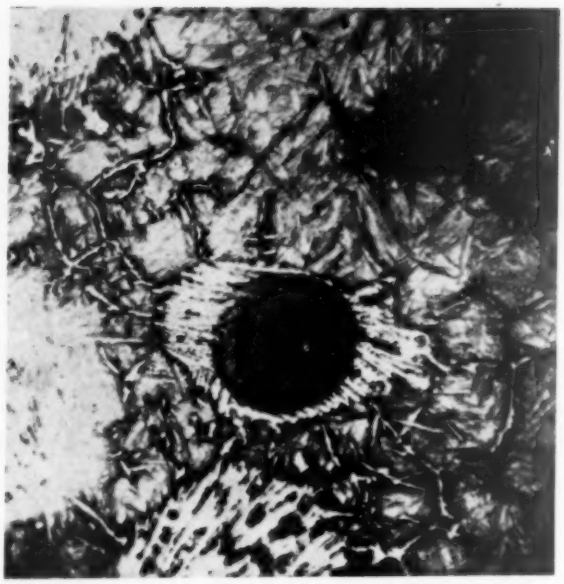
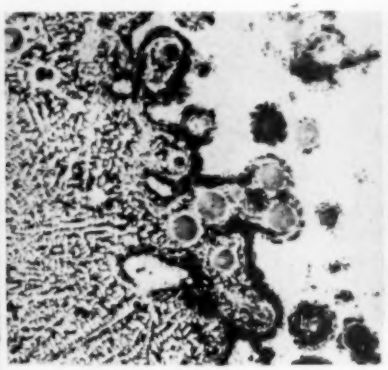


Fig. 7 A liquid network extending ahead of the main liquid interface. Nital etch. 500 ×

(*a*)



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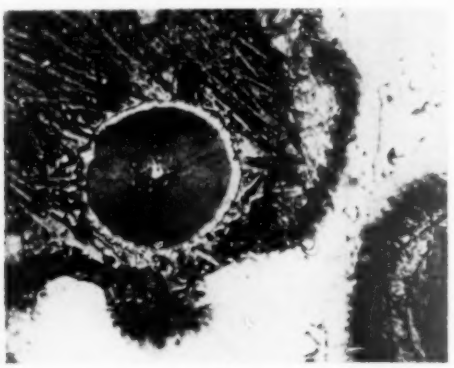

(*c*)

Fig. 8 (a) An arc pass showing white ferrite rings around each nodule. Nital etch. 100 ×

Fig. 8 (b) An arc pass with a sodium-picrate etch. White rings are ferrite. 100 ×

Fig. 8 (c) A ferrite ring with a sodium-picrate etch. 500 ×

Fig. 9 Region 3. Structure is nodular graphite, martensite, carbide plus eutectic, and martensite. Nital etch. 500 ×

Under faster cooling rates and with less favorable composition, the graphitization proceeded as before except that the region depleted in carbon by graphitization never reached a low enough carbon value to prevent it from transforming to martensite at lower temperatures. Such a structure can be seen in Fig. 9. The structure in this case is: nodule, martensite, carbide plus eutectic, and martensite.

Region 4. This region was defined as that of complete fusion, i.e., where liquid interfaces from neighboring nodules had joined. Figure 5 represents the carbon gradient in this region. The structure (Fig. 6 (*b*)) of this zone was that of a hypo- or hypereutectic white cast iron, depending on the base plate composition.

Vickers Microhardness Tests

Only the following general observations could be made from microhardness data due to the inherent inaccuracies involved in the tests.

1. The hardness of Region 4 was very high, around VHN 800 to 1000.
2. The hardness of Region 3 was very high (VHN 800) where the liquid existed, and slightly lower (VHN 600) in the martensitic areas.

Effect of Variables

Base plate composition and energy input per unit length of pass affected structure only in detail, for example, as in graphitization in Region 3 as previously noted.

Preheat above 600° F showed a definite effect on the structures of Regions 3 and 2. Lower preheats showed no significant effect.

Region 3. High preheat temperature (800° F) resulted in pronounced tendency toward liquid penetration along the grain boundaries. Since this liquid yields a carbide network on cooling, it can easily be seen that such a structure is not desirable. Figure 10 shows this extensive carbide network. Other work* has noted decreased machinability with high preheats, an effect probably attributable to this carbide network.

Region 2. With high preheats, the austenite transformation product of this region was very fine pearlite instead of martensite. The width of this region increased with increasing preheat.

In the samples given a ferritizing postheat treatment, the following changes were noted in Regions 4, 3 and 2.

Region 2. Most of the carbon in the austenite transformation product seemed to redeposit on the nodules.

* Unpublished work done by The International Nickel Co., Inc.

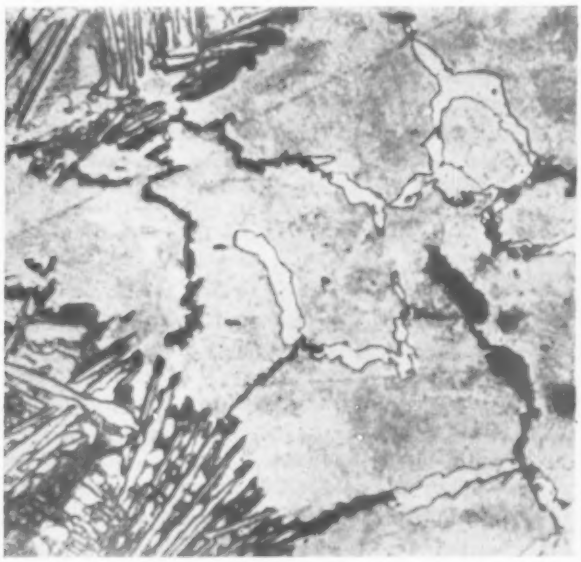

Fig. 10 (a) Extensive carbide network resulting from high preheat. Sodium-picrate etch. 500 ×

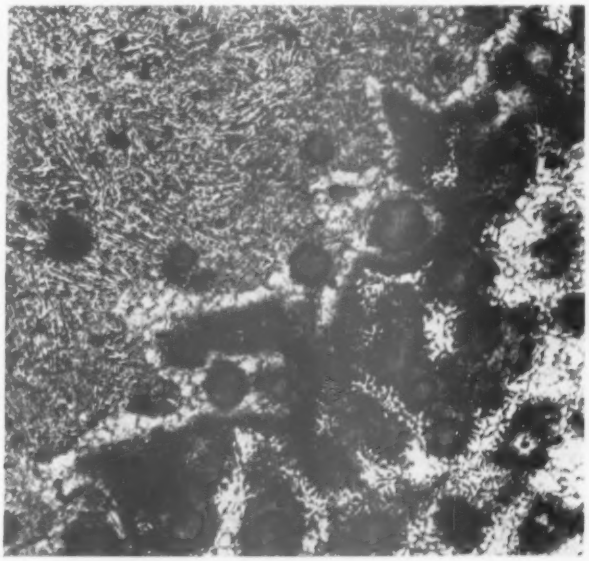

Fig. 10 (b) Carbide network and extensive Region 2 resulting from high preheat. Nital etch. 100 ×

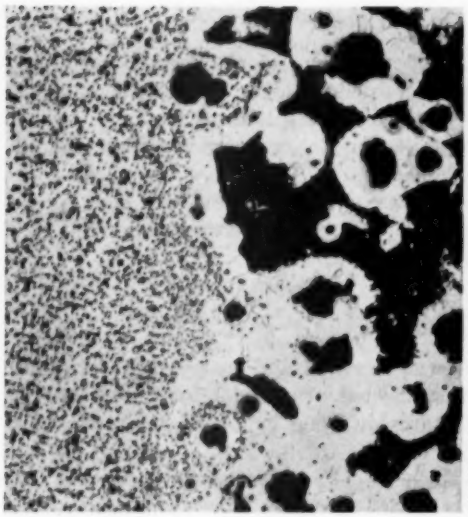

Fig. 11 A typical pass after postheat treatment. Structure is nodular graphite in ferrite with pearlite patches. Nital etch. 100 ×

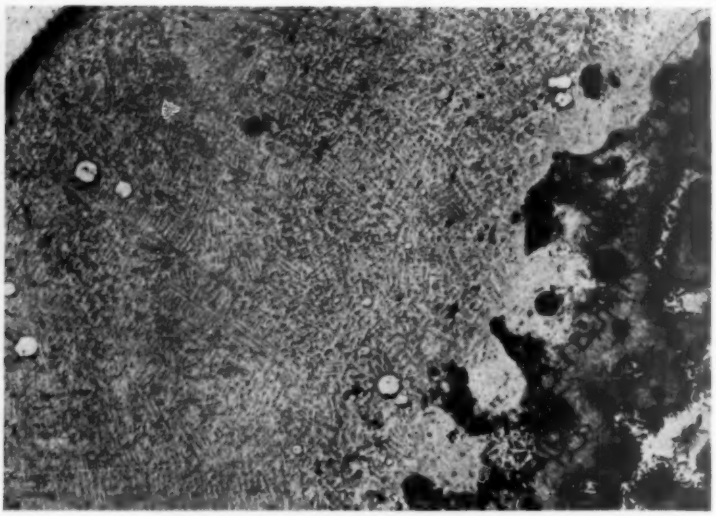

Fig. 12 A phosphor-bronze weld. Region 5 is at the upper left. Next is Region 4, which is mainly carbide. Toward the right are Regions 3 and 2, respectively

However, some carbon appeared as tiny nodules of graphite located randomly around the spherulites.

Region 3. This region appeared similar to Region 2 except that graphitization seemed to be in rings around each nodule, presumably corresponding to the rings where liquid was present (see Fig. 11).

Region 4. In this region, graphitization occurred at a multitude of centers. Work done at The International Nickel Co. has shown this fine nodular structure to have poor ductility, and therefore little can be gained by a complete ferritizing postheat treatment, even if it were commercially feasible.

Welds and Weld Passes

The previous discussion has been confined to arc passes where no filler metal was deposited, but serves equally well to explain structures observed in weld passes if an addition region is considered.

Region 5. This was defined as the fused filler metal.

By examining the mechanism of melting of the base plate, it may be seen that if Region 4 is present all other regions must be present. Similarly, if Region 3 is present, Regions 2 and 1 must be present. In short, if, in applying the filler metal, the base plate melts, all regions previously discussed must be present.

When melting of the base plate occurs during welding, there are actually two distinct fusion regions (5 and 4) and one partial fusion region (3). This fact may be accounted for in the following way:

As the filler metal hits the surface of the plate, a point on the surface attains its peak temperature. Some melting may or may not occur immediately. At any rate, points behind the plate surface are still heating up and liquid interfaces are starting to advance from every nodule. However, heat is being extracted rapidly from the filler metal, which causes a surface skin to freeze before the points behind the surface have been at a high temperature long enough for the liquid interfaces to join. Hence, Region 4 is not completely liquid until Region 6 has started to freeze. Figure 12 shows all the regions present in a phosphor-bronze weld.

All the runs except No. 23 (Table 2) showed the same regions present as in the phosphor-bronze weld. Run 23 was actually a brazed joint and therefore Region 4 was absent, since only partial fusion of the base plate occurred.

Region 4 is probably the most detrimental to the finished weld since it is a very hard, continuous and brittle carbide. Region 3, while containing a hard carbide, may not damage weld strength appreciably since it is not continuous except when high preheats are used and a grain boundary network forms. The undesirable effects of martensite in the other regions can be partially nullified by postheating with an oxy-acetylene flame. However, such a postheat treatment has no effect on the carbide regions.

Joint Strengths

Although no quantitative tests were made, all the joints were found to be brittle enough to be easily fractured with a hammer. In addition, none of the joints was machinable to the extent that it could be sectioned with a hack saw. Metallographic examination of several fractured joints showed the fracture to lie mostly in the continuous carbide of Region 4.

The effect of preheat and postheat treatment was the same in the case of welds as for arc passes. Preheat gave the additional advantage of lessening bead cracking.

CONCLUSIONS

The results of the foregoing study have failed to show the way toward a completely satisfactory structural joining method. However, it is possible to predict in what direction the answer does lie, and several directions in which it cannot lie.

Any method which melts the base plate upon application of filler metal will cause a hard, continuous carbide zone and is therefore undesirable. In fact, any method that heats the base plate above the eutectic temperature will result in localized melting about the nodules, and subsequent formation of hard carbides.

The type of filler rod has little effect toward eliminating the carbide region since part of the base plate becomes liquid after the filler metal has started to freeze.

In addition, the problem will never be completely solved by use of preheat, postheat treatment or by juggling other welding variables such as welding speed and energy input.

From a metallurgical point of view, the solution seems to lie with a brazing process. Further, the filler metals are limited to those which melt below the eutectic temperatures of commercial nodular cast irons (around (2300° F). In addition, the filler metal must have comparable strength and ductility to that of the base plate and also must be inexpensive. No material exists which fulfills all the qualifications, but aluminum bronze can qualify in every respect except cost.

ACKNOWLEDGMENTS

The authors wish to express their thanks to The International Nickel Co. for technical information and to the American Brake Shoe Co. for helpful advice and for financial support of this work.

Semiautomatic Inert-Gas Metal-Arc Welding of Aluminum Alloys

Discussion by H. Udin

The subject paper is a valuable contribution, and should become part of the stock-in-trade of every welding engineer designing high-strength aluminum weldments. There are, however, two disturbing items in the test procedure, both having to do with the proper approach to the physical testing of duplex materials.

The engineering stress-strain curve, in the region between the proportional limit and the incidence of necking, can only be interpreted meaningfully if the material under test is reasonably homogeneous and isotropic. Transverse weld tension coupons, on the other hand, are not even approximately homogeneous. For example, with the combination "43 filler–618-T6 plate" there are, even on the roughest macro scale, three distinct zones: the weld, the overaged bands and the unaffected stock. For such an assembly, 0.2% offset yield strength has no engineering significance. The 0.002 ipi of permanent deformation indicated at this stress will be distributed in quite an unpredictable way among the three zones. Furthermore it is obvious that the strain distribution at 0.002 average strain will vary in an unpredictable fashion with filler-stock combination, with welding procedure and, even worse, with gage length.

If we must extract something more than proportional limit and joint ultimate from the transverse weld tensile test rather elaborate procedures are necessary. For instance, we might bond two transverse gages on the weld and the heat-affected zone and a third gage longitudinally on the stock. Interpretation of the three stress-strain curves so obtained would be difficult because of plastic interaction among the three regions, but at least it could be made reasonably rational.

In guided bend qualification testing the situation is even more confused. While this is a minor point in the subject paper, I bring it up because the authors, by using guided bend qualification on the combination "43S–61S-T6," apparently approve of a test whose validity is highly questionable.

Assume for the moment a homogeneous $^1/_4$-in. plate bent in a standard test jig to $r = 3t$. If the neutral axis remains at the center of the bar the maximum fiber strain will be $(4-3.5)/3.5$ or 14%. However, the guided bend test does not subject a coupon to pure bending. There is more or less of a deep-drawing ef-

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Paper by C. T. Gayley, Joseph R. Girini and Walter H. Wooding was published in THE WELDING JOURNAL, 32 (4), Research Suppl., 179-s to 190-s (1953).

fect, depending on the coefficient of friction between the coupon and the shoulders of the jig. I have often found in the absence of lubrication that the neutral bend axis coincides with the punch-coupon interface (determined by the ratio of lateral contraction at the outer radius to lateral extension of the surface in contact with the punch). In this case the outer fiber strain is $(4 - 3)/3$ or 33%! Thus we are asking a filler metal that only shows 14% elongation in the all-weld-metal tensile test to pass a bend test that subjects it to some unknown elongation between 14 and 33%.

So what do we do about it? We recall that this is a duplex material, and we anneal—not the filler metal; it's unannealable—but the stock and HAZ. How does this permit the coupon to pass the test? The filler metal is no more ductile and the bend radius is still the same. Or is it? Every guided bend jig has some clearance, and if we can make the stock and HAZ softer than the weld, then the root of the bend will bear on the punch while the edges of the hard zone bear on the sides of the jig. There will be more bending in the HAZ than in the weld itself. We say that we "anneal to Bhn 35 to more nearly match the hardness of the filler metal," but 43S wire as deposited, and after annealing, has a hardness of 40 Brinell. As proof of the pudding, the unannealed coupon breaks, not in the hard base metal, but in the weld, usually dead center. Since the bend radius cannot be less than $3t$, no matter how hard the stock, it must be greater than $3t$ with softened stock. (Incidentally, I wonder how many $^1/_4$-in. aluminum coupons have been tested in the standard $^3/_8$ in., $r = 2t$ guided bend jig, which has the same punch dimensions as the special $^1/_4$ in., $r = 3t$ jig.) Let us recognize the guided bend test for what it is, a test to detect stress-concentrating defects in otherwise amply ductile metal. Let's not use it as a weld-metal ductility test.

Authors' Reply

The authors are in full accord with the comments of Mr. Udin relative to the lack of homogeneity in transverse weld test coupons and did demonstrate this fact by the use of hardness surveys which were presented in Figs. 16 and 17 of the subject paper. They are also cognizant of the fact that, because of this lack of homogeneity, the length of gage in the tension test will influence the offset yield strength determined by stress-strain curves. However, there is another important factor which Mr. Udin failed to mention and that is because of the lack of homogeneity, the determination of the proportional limit or the stress at which the initial yielding occurs is influenced by the sensitivity of the extensometer.

In determining the stress-strain data presented in the subject paper, the 8-in. gage length extensometer was selected not only for its convenience in spanning the welded joint but also because of its sensitivity when compared with extensometers of shorter gage. The sensitivity of the extensometer used was direct reading to 0.00002 in. in 8-in. gage length. The proportional limit indicated on the several curves is that stress where strain has exceeded the limit of proportionality by 0.00001 in. in the 8-in gage length. Had the sensitivity of the extensometer been of lower order, the proportional limits determined for the several types of joints would have been of higher value.

It was not the purpose of the paper to introduce new or novel test methods in determining the transverse tensile properties of welded joints. The stress-strain curves were presented to illustrate the yielding characteristics of the several types of joints for each filler-stock combination. These characteristics are important to the design of welded structures utilizing nonferrous metals. Generally, such design is based on joint efficiency; the ratio of the ultimate strength of the welded joint to that of the prime or parent metal. Therefore, it was not for the purpose of establishing limiting values for design that the proportional limits and 0.2% offset yield strengths were indicated. Rather, it was intended that these values serve as terminal points in the study of the yielding characteristics of the joints under consideration.

The method proposed by Mr. Udin to determine the yielding characteristics in tension of transverse weld test coupons appears most interesting to the authors and they would appreciate a demonstration of the method together with an interpretation of the stress-strain curves so obtained.

The authors regret that their presentation concerning the use of the guided bend test lacked sufficient clarity to prevent confusion. For many years, it has been standard practice in the welding industry to use the guided bend test as a "go-no go" test for the qualification of welders. As indicated by Mr. Udin, it is a test to detect stress-concentrating defects in otherwise amply ductile metal. In this role, it indicates the ability of the welder to produce welds free of such defects. Reference made to this test was for the purpose of establishing the minimum condition for the qualification of welders to be used in depositing the various weldments under consideration in the paper. There is no mention in the paper nor was there any intention to use the guided bend test as a means for determining weld ductility.

Mr. Udin seems to be further confused concerning the method of preparing weld test coupons for the guided bend test. Prior to welding the test assemblies, the 61S-T6 plate material was annealed to a hardness of 34–36 Brinell. This softened plate material was then used as the parent metal in preparing the weld test coupons which were subjected to the guided bend test in the as-welded condition. This method, which was established as a result of a rather extensive investigation, has been used for the past several years with considerable success in the training and qualifying of welders for welding 61S-T6 aluminum alloy with 43S aluminum alloy filler metal using the inert-gas shielded metal-arc welding process.

An Investigation on Peening

Results of modified Charpy impact tests and hardness surveys show the effects of peening mild steel plate material and deposited weld metal

by P. L. Calamari, F. J. Crum and G. W. Place

INTRODUCTION

THE effective use of peening to reduce residual welding stresses, to prevent cracking in highly restrained weldments or to overcome distortion has long been a subject of controversial discussion among various authors and welding engineers. This present investigation, sponsored by the Welding Research Council and under the general guidance of a seven-member Peening Committee, has been carried out at the American Bureau of Shipping Laboratory in an attempt to evaluate the effects of some of the many variables of peening.

Whereas most of the previous peening investigations, such as carried out at the University of California[1] and at the University of Washington[2] in 1946, were concerned with the effect of peening on the residual stresses in weldments, this present investigation has been confined primarily to the effect of peening on some of the physical and metallurgical properties of worked metal. It is hoped that the results of this investigation will be useful in verifying or supplementing code requirements dealing with the optimum temperatures for peening, the restriction of peening to intermediate weld layers or other controls on peening variables which can be adopted in practice.

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WELDING—PEENING EQUIPMENT

The development of the special welding-peening machine used in this investigation was completely described in a preliminary paper delivered by J. Lyell Wilson at the SOCIETY's annual meeting in Cleveland in October 1949 and published in the March 1950 WELDING JOURNAL. The particular advantage of this machine is that it provides the necessary mechanical control to insure consistent duplication of the peening process itself.

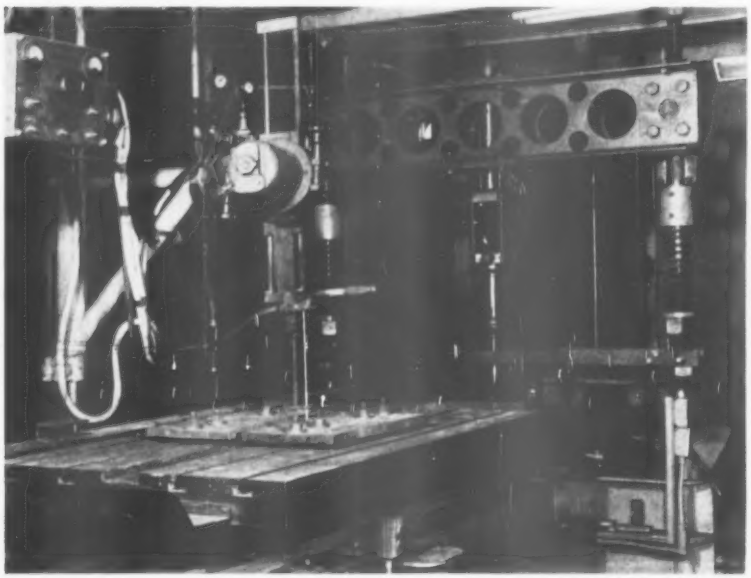

Fig. 1 Welding-peening machine

An over-all view of the welding-peening machine is shown in Fig. 1. The work table of the machine travels on two steel rails and is driven by a lead screw at any desired speed of from $^1/_2$ to 20 ipm through a gear transmission and ratiomotor. An automatic welding head of the stick feeder type is located above the work table about 5 ft. forward of a pneumatic peening hammer which is supported at the correct height above the work table through a floating cross box beam. The peening tool itself operates through a loosely fitting guide which helps to keep the path of peening in a straight line. Very simply stated, the procedure consists of clamping a sample to the top of the work table, passing it under the automatic stick feeder for the welding operation and then

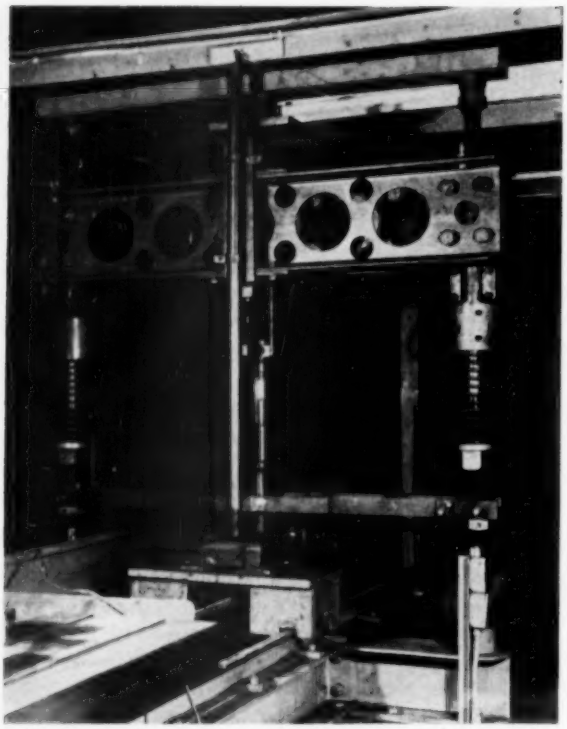

Fig. 2 Calibration box in position under brass tube

on under the pneumatic hammer for the peening operation.

Three different weight hammers, which we have designated as light, medium and heavy, can be used for peening. The corresponding manufacturer's* designations for these three hammers are listed as follows:

Light	No. 1 chipping hammer
Medium	No. CP411 hammer
Heavy	No. 60 large hammer

* Chicago Pneumatic Tool Co.

The capacity of the compressor and air storage tank is such that the peening hammers can be operated steadily at various air pressures up to 105 psi. The riding load can be varied by adding weights to the top of the air hammer holding jig.

CALIBRATION OF HAMMERS

The method for calibrating the frequency and energy output of the peening hammers has been changed somewhat from that originally used and described in the preliminary paper. The method now used is, we believe, more direct and quantitative checks on hammer operation can now be conveniently made—daily or even before and after each peening pass. Originally, the energy output of the hammers was determined by measuring and calculating the energy values obtained from the compression of copper plugs under static loading as compared with their compression under the dynamic loading of the peening tool. The frequency of the hammers was originally determined directly from oscilloscope signals actuated by two strain gages attached to the peening tool.

In the present calibration method, both the energy output in foot-pounds per blow and the frequency in blows per minute are determined by means of an all-welded steel calibration box 6 in. long by 6 in. wide by $2^1/_4$ in. high. This box is completely filled with distilled water and a dynamic Bakelite strain gage, type CBD-10, is cemented to the bottom plate of the box and connected electrically to an oscilloscope. A free space is provided beneath the bottom plate in way of the strain gage by mounting the calibration box on two $^1/_2$-in. thick steel flaps, as can be seen in Fig. 2.

The "yardstick" or base line for energy values is

		AVERAGE BLOWS PER MINUTE AND ENERGY PER BLOW							
HAMMERS	RIDING LOAD IN POUNDS	AIR PRESSURE 60 PSI		AIR PRESSURE 75 PSI		AIR PRESSURE 90 PSI		AIR PRESSURE 105 PSI	
		B.P.M.	ENERGY FT. LBS. PER BLOW	B.P.M.	ENERGY FT. LBS. PER BLOW	B.P.M.	ENERGY FT. LBS. PER BLOW	B.P.M.	ENERGY FT. LBS. PER BLOW
LIGHT	0	2565	1.0	2880	1.08	3060	1.90	3240	2.47
	50	2610	1.65	2880	2.17	3240	2.25	3420	2.47
	100	2610	1.83	2880	2.23	3150	2.78	3240	3.65
	150	2610	2.03	2880	2.43	3060	3.02	3240	4.28
MEDIUM	0	1447	2.36	1586	4.42	1672	6.0	1757	6.98
	50	1449	3.56	1583	4.29	1672	5.37	1757	7.33
	100	1447	3.69	1586	5.64	1672	5.72	1757	8.04
	150	1449	4.23	1586	5.33	1672	6.37	1757	8.25
HEAVY	0	1200	11.6	1331	12.7	1416	11.8	1472	11.4
	50	1200	13.5	1309	14.9	1392	16.4	1416	18.1
	100	1200	14.9	1309	16.5	1392	17.1	1440	19.5
	150	1142	15.9	1288	17.1	1392	17.9	1440	19.8

Fig. 3 Peening hammer calibration data

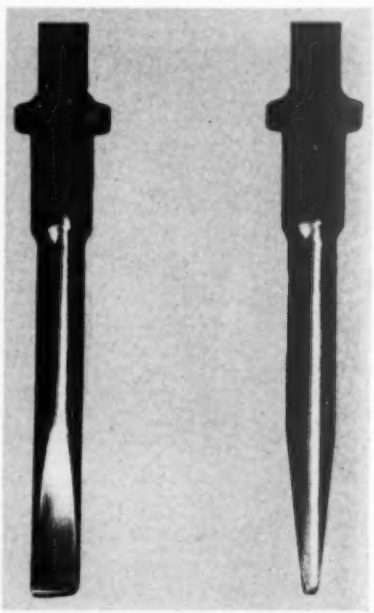

Fig. 4 Chisel-shaped peening tool

obtained by dropping a known weight from a known height through a freely fitting brass tube on to the top of the calibration box (Fig. 2). The blow of the dropped weight results in a slight deflection of the bottom plate, which is registered through the strain gage as a signal or blip on the oscilloscope screen. It was found that, for any one dropped weight, the height of the blip increases in almost a straight-line relationship with the height of drop. In other words, the height of the blip can be used as a measure of energy expressed in foot-pounds per blow. A picture of each blip is taken with a 35-mm camera mounted in front of the oscilloscope screen and this picture is enlarged to a known magnification so that the height of the blip can be accurately measured. Three different weights were made for this part of the calibration so that their weight, length, hardness and diameter were the same as the different peening tools used in the three different size pneumatic hammers. A curve plotting foot-pounds per blow versus height of blip was then obtained for each of the three different dropped weights.

The calibration box is then transferred under the peening tool and each of the hammers in turn can be operated at any desired air pressure and with any desired riding load. The resulting blips on the oscilloscope screen are photographed and enlarged to the same magnification as previously used, and the average height of these blips is then compared with the corresponding dropped weight curve. The approximately average foot-pounds per blow during peening is thus determined for each condition of operation. Although there is usually some variation in the height of the blips that are obtained from any one set of hammer-operating conditions, it is felt that the average energy delivered is within the limits of duplication that can be expected from a pneumatic peening hammer, which admittedly is not a precision tool.

The frequency of the hammers in blows per minute can be determined directly from the frequency of the blips on the oscilloscope screen and in this respect the present method of calibrating for hammer frequency is similar to that formerly used, other than in the location of the strain gages.

The average results obtained from one series of hammer calibrations are shown in Fig. 3. For these conditions of calibration, it may be noted that the blows per minute (BPM) decreased with the use of heavier hammers and increased with higher operating air pressures. The blows per minute were not appreciably or consistently affected by the hold down pressure (riding load) provided the pressure was sufficient to steady the frequency of the hammer and yet not too great to interfere with its operation. In general, the energy per blow increased with the use of heavier hammers, higher operating air pressures and heavier riding loads.

PEENING TOOL

The first peening tool tried in this investigation was one tapered to a $^1/_4$-in. ball point and, while such a pointed tool might be entirely satisfactory for manual peening, it was unsatisfactory for our automatic peening method due to the fact that it dug deep holes in the peened material and there was danger of snapping the tool. This led to the development of a chisel-shaped peening tool which is shown in Fig. 4. This tool has a $^1/_4$-in. diam. nose with a gradual relief at the leading end. When peening was carried out with the length of the nose parallel to the direction of travel, a shallow and reasonably smooth groove was produced in the peened material. This eventually led to the development of a special Charpy-type impact specimen in which the natural notch produced by peening is used as the notch of the impact specimen.

IMPACT SPECIMEN

A sketch of the modified Charpy impact specimen used in this investigation is shown in Fig. 5. The particular advantage of this type of specimen is that none of the peened metal at the base of the notch is removed or disturbed in machining the impact specimens. The distance back of the notch (0.197 in.), the width (0.394 in.) and the length (2.165 in.) were made to agree with the standard Charpy specimen, although no correlation with standard Charpy results is intended. The depth of the notch (0.028 in.) was arrived at arbitrarily as the deepest notch that could be consistently obtained in the finished machine samples from the relatively shallow groove produced by peening at the fastest travel rate used in this investigation (20 ipm).

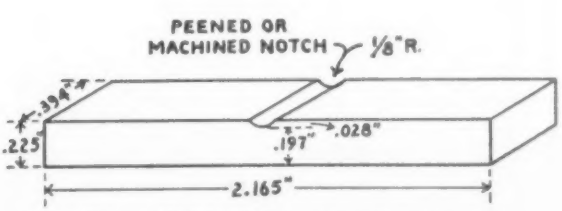

Fig. 5 Modified Charpy impact specimen

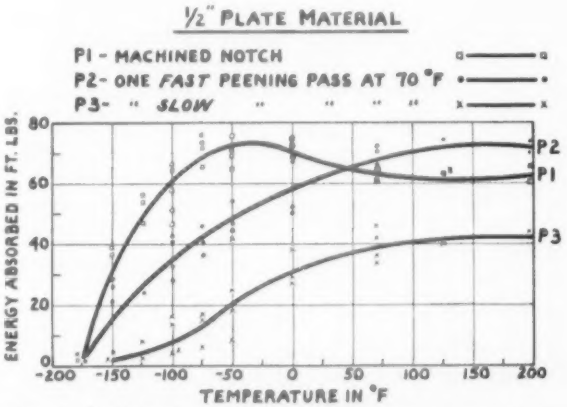

Fig. 6 Machined notch vs. notches peened at 70° F. Impact curves. Prime plate

IMPACT TESTS ON PRIME PLATE

A considerable amount of preliminary work was carried out on prime plating to determine if satisfactory impact transition temperature curves could be obtained —from which some of the variables of peening could be evaluated. The plate samples used were 18 in. long by $2^1/_2$ in. wide by $^1/_2$ in. thick from a heat of 0.19 carbon, 0.73 manganese semikilled steel. It became obvious as the program continued that it would not be possible to investigate all of the variables of hammer operation, together with the many possible variables of peening, in any reasonable length of time. It was decided therefore to use only the medium hammer at 90 psi air pressure and no riding load, with a fast and a slow rate of peening travel; fast peening being at a travel rate of 20 ipm and slow peening at 5 ipm. The slow travel rate, therefore, results in four times as many peening blows per unit of length as does the fast travel rate.

The plate samples were first descaled by pickling, then clamped to the work table of the machine and passed under the peening hammer so that a groove was peened lengthwise along the centerline of each sample. Impact specimens were then machined from thees peened samples and tested, and temperature versus energy absorption curves were plotted from the test results. For comparison, impact specimens having the same geometry but with a machined notch instead of a peened notch were also prepared and tested. Due to variations in the groove depth and flatness of any one plate sample after peening these impact specimens required individual machining and their preparation was very time consuming.

The results obtained on prime plate samples peened fast (P2) and slow (P3) with a single peening pass at 70° F, as compared with an unpeened sample having a machined notch (P1), are shown in Fig. 6. With fast peening there is a slight loss in energy absorption at the lower testing temperatures as compared with the machined notch. With slow peening the energy absorption is considerably less than for either fast peening or the machined notch. The peened notches are not as smooth nor as uniform as the machined notch and this quite possibly may affect some of the individual energy values obtained. However, these three particular tests have been repeated several times and the same general

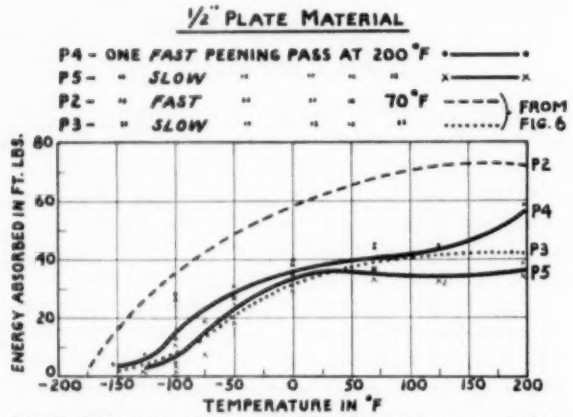
½" PLATE MATERIAL
P4 - ONE FAST PEENING PASS AT 200°F
P5 - " SLOW " " " "
P2 - " FAST " " " 70°F
P3 - " SLOW " " " "
FROM FIG. 6
ENERGY ABSORBED IN FT. LBS.
TEMPERATURE IN °F
P2
P4
P3
P5

Fig. 7 Effect of peening at 200° F. Impact curves. Prime plate

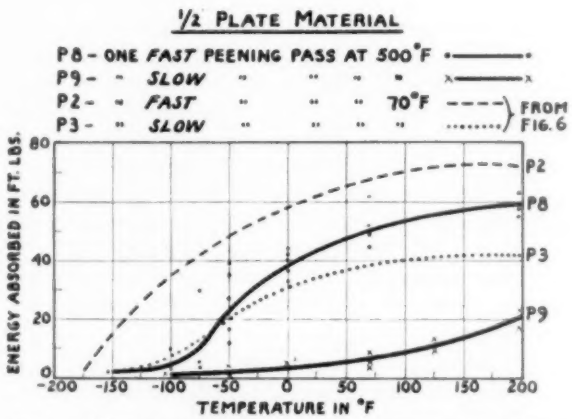
½ PLATE MATERIAL
P8 - ONE FAST PEENING PASS AT 500°F
P9 - " SLOW " " " "
P2 - " FAST " " " 70°F
P3 - " SLOW " " " "
FROM FIG. 6
ENERGY ABSORBED IN FT. LBS.
TEMPERATURE IN °F
P2
P8
P3
P9

Fig. 9 Effect of peening at 500° F. Impact curves. Prime plate

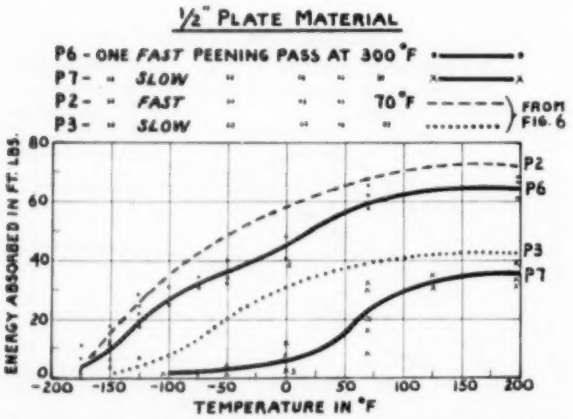
½" PLATE MATERIAL
P6 - ONE FAST PEENING PASS AT 300°F
P7 - " SLOW " " " "
P2 - " FAST " " " 70°F
P3 - " SLOW " " " "
FROM FIG. 6
ENERGY ABSORBED IN FT. LBS.
TEMPERATURE IN °F
P2
P6
P3
P7

Fig. 8 Effect of peening at 300° F. Impact curves. Prime plate

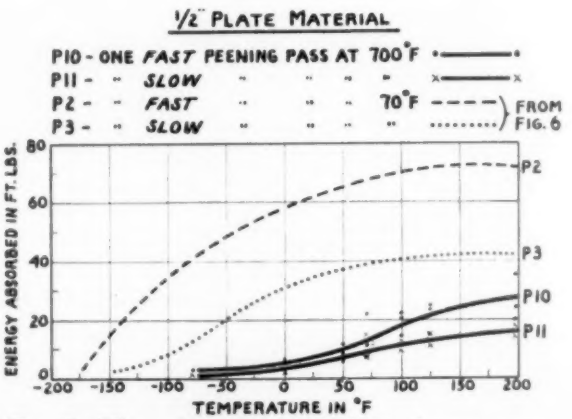
½" PLATE MATERIAL
P10 - ONE FAST PEENING PASS AT 700°F
P11 - " SLOW " " " "
P2 - " FAST " " " 70°F
P3 - " SLOW " " " "
FROM FIG. 6
ENERGY ABSORBED IN FT. LBS.
TEMPERATURE IN °F
P2
P3
P10
P11

Fig. 10 Effect of peening at 700° F. Impact curves. Prime plate

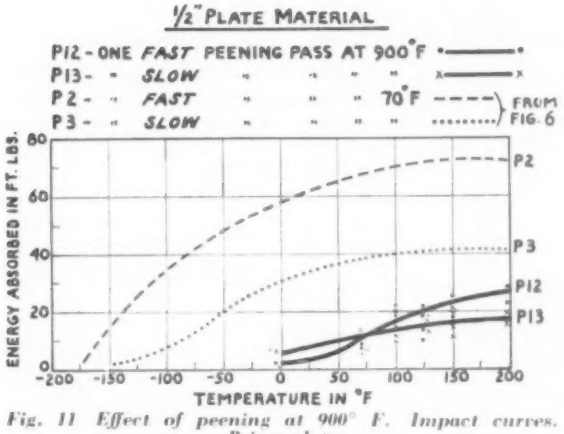
½" PLATE MATERIAL
P12 - ONE FAST PEENING PASS AT 900°F
P13 - " SLOW " " " " "
P2 - " FAST " " " " 70°F
P3 - " SLOW " " " " "
FROM FIG. 6
ENERGY ABSORBED IN FT. LBS.
TEMPERATURE IN °F
P2
P3
P12
P13

Fig. 11 Effect of peening at 900° F. Impact curves. Prime plate

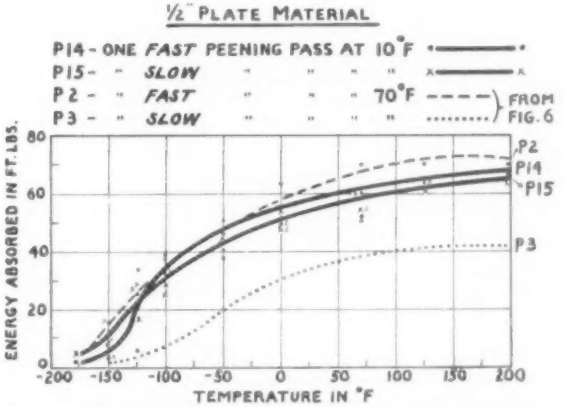
½" PLATE MATERIAL
P14 - ONE FAST PEENING PASS AT 10°F
P15 - " SLOW " " " " "
P2 - " FAST " " " " 70°F
P3 - " SLOW " " " " "
FROM FIG. 6
ENERGY ABSORBED IN FT. LBS.
TEMPERATURE IN °F
P2
P14
P15
P3

Fig. 12 Effect of peening at 10° F. Impact curves. Prime plate

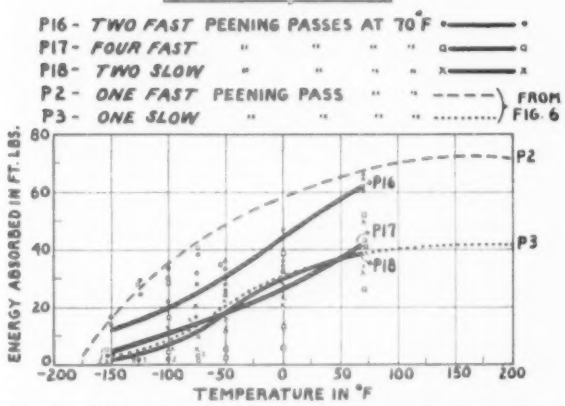
½" PLATE MATERIAL
P16 - TWO FAST PEENING PASSES AT 70°F
P17 - FOUR FAST " " " "
P18 - TWO SLOW " " " "
P2 - ONE FAST PEENING PASS " "
P3 - ONE SLOW " " " "
FROM FIG. 6
ENERGY ABSORBED IN FT. LBS.
TEMPERATURE IN °F
P2
P16
P17
P18
P3

Fig. 13 Effect of multiple peening passes. Impact curves. Prime plate

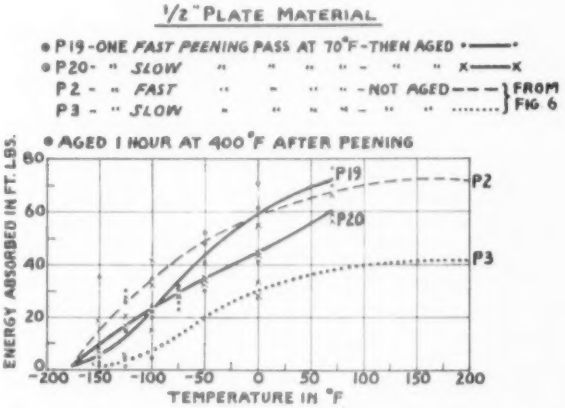
½" PLATE MATERIAL
P19 - ONE FAST PEENING PASS AT 70°F - THEN AGED
P20 - " SLOW " " " " " - " "
P2 - " FAST " " " " - NOT AGED
P3 - " SLOW " " " " - " "
FROM FIG 6
AGED 1 HOUR AT 400°F AFTER PEENING
ENERGY ABSORBED IN FT. LBS.
TEMPERATURE IN °F
P19
P2
P20
P3

Fig. 14 Effect of aging treatment after peening. Impact curves. Prime plate

trends have been obtained. The temperature at which each curve crosses the 15 ft-lb energy level has been arbitrarily chosen as the transition temperature. In Fig. 6, therefore, the transition temperature for the machined notch (unpeened material) is −165° F, for fast peening it is −150° F, and for slow peening −70° F. No attempt has been made in this investigation to judge the transition temperatures by the percent of cleavage and shear in the fractured impact specimens.

To determine the effect of peening at various temperatures and to further check the testing method, additional samples of prime plating were peened with a single peening pass at 10, 200, 300, 500, 700 and 900° F with results as shown in Figs. 7 to 12, inclusive. Samples were also peened at 70° F with two fast peening passes, four fast peening passes and two slow peening passes with results as shown in Fig. 13. The effect of a 1-hr. aging treatment at 400° F after peening prime plate samples at 70° F is shown in Fig. 14.

HARDNESS TESTS ON PRIME PLATE

Diamond Pyramide Hardness tests using a 5000-g load were made on one unbroken impact specimen from each of the 20 prime plate samples. The hardness indentations were made in a row extending from 0.02 in. below the base of the notch to the back of the impact specimen with a spacing of 0.04 in. between each indentation. The results of these hardness surveys are shown in Figs. 15 to 23, inclusive.

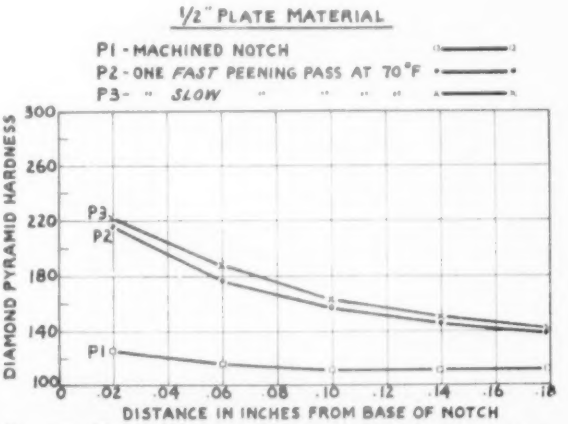
½" PLATE MATERIAL
P1 - MACHINED NOTCH
P2 - ONE FAST PEENING PASS AT 70°F
P3 - " SLOW " " " "
DIAMOND PYRAMID HARDNESS
DISTANCE IN INCHES FROM BASE OF NOTCH
P3
P2
P1

Fig. 15 Machined notch vs. notches peened at 70° F. Hardness curves. Prime plate

SUMMARY OF PRIME PLATE TEST DATA

A summary of all the data obtained from the tests on prime plating is given in Fig. 24 which shows the average depth of the peened grooves, the transition temperature based on 15-ft-lb energy absorption and the hardness at a point 0.020 in. under the base of the notch. From this table the following observations can be made:

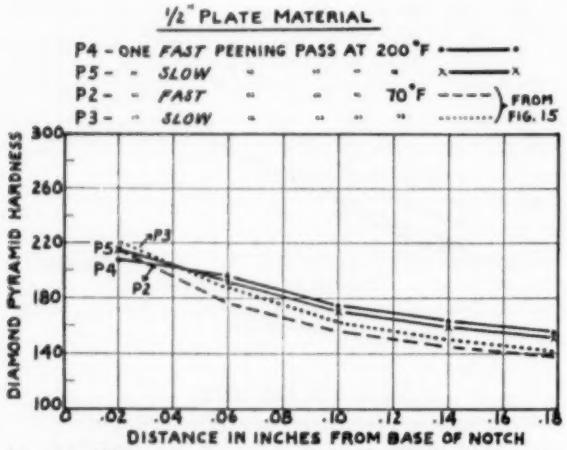
½" PLATE MATERIAL
P4 - ONE FAST PEENING PASS AT 200°F
P5 - " SLOW " " " "
P2 - " FAST " " " 70°F
P3 - " SLOW " " " "
FROM FIG. 15
DIAMOND PYRAMID HARDNESS
DISTANCE IN INCHES FROM BASE OF NOTCH

Fig. 16 Effect of peening at 200° F. Hardness curves. Prime plate

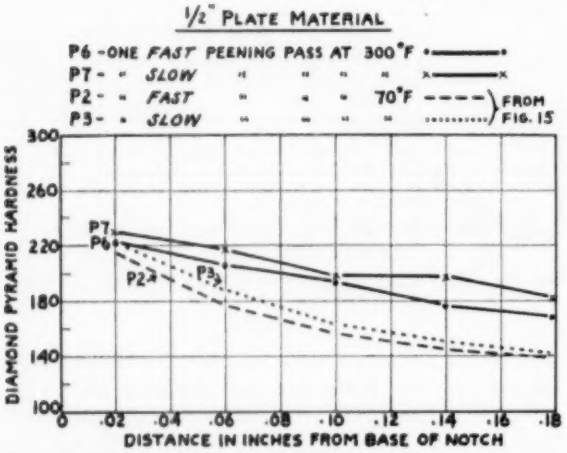
½" PLATE MATERIAL
P6 - ONE FAST PEENING PASS AT 300°F
P7 - " SLOW " " " "
P2 - " FAST " " " 70°F
P3 - " SLOW " " " "
FROM FIG. 15
DIAMOND PYRAMID HARDNESS
DISTANCE IN INCHES FROM BASE OF NOTCH

Fig. 17 Effect of peening at 300° F. Hardness curves. Prime plate

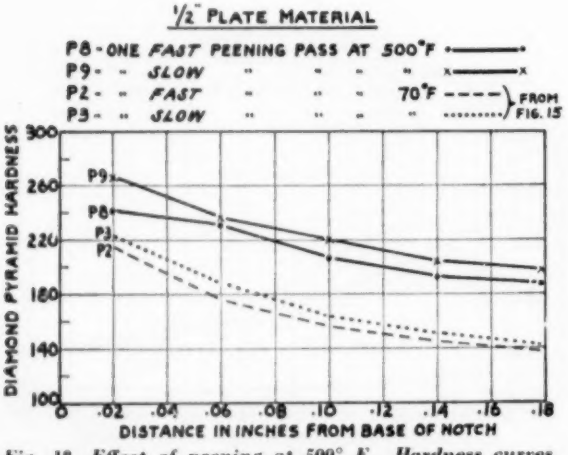
½" PLATE MATERIAL
P8 - ONE FAST PEENING PASS AT 500°F
P9 - " SLOW " " " "
P2 - " FAST " " " 70°F
P3 - " SLOW " " " "
FROM FIG. 15
DIAMOND PYRAMID HARDNESS
DISTANCE IN INCHES FROM BASE OF NOTCH

Fig. 18 Effect of peening at 500° F. Hardness curves. Prime plate

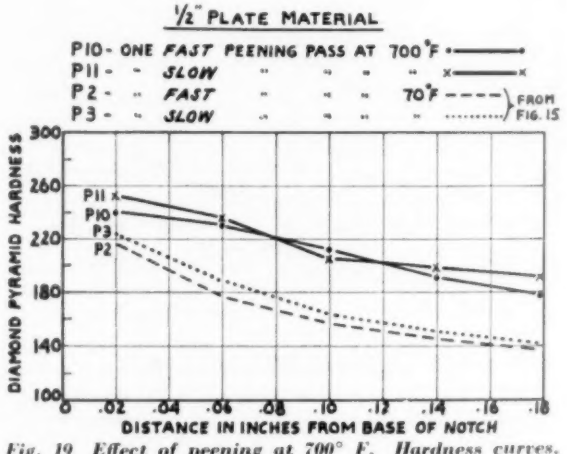
½" PLATE MATERIAL
P10 - ONE FAST PEENING PASS AT 700°F
P11 - " SLOW " " " "
P2 - " FAST " " " 70°F
P3 - " SLOW " " " "
FROM FIG. 15
DIAMOND PYRAMID HARDNESS
DISTANCE IN INCHES FROM BASE OF NOTCH

Fig. 19 Effect of peening at 700° F. Hardness curves. Prime plate

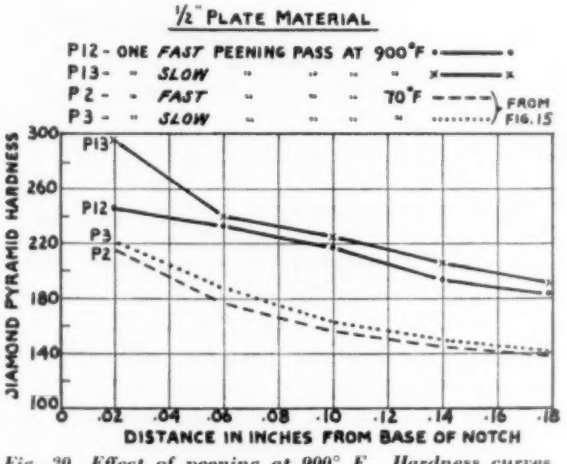
½" PLATE MATERIAL
P12 - ONE FAST PEENING PASS AT 900°F
P13 - " SLOW " " " "
P2 - " FAST " " " 70°F
P3 - " SLOW " " " "
FROM FIG. 15
DIAMOND PYRAMID HARDNESS
DISTANCE IN INCHES FROM BASE OF NOTCH

Fig. 20 Effect of peening at 900° F. Hardness curves. Prime plate

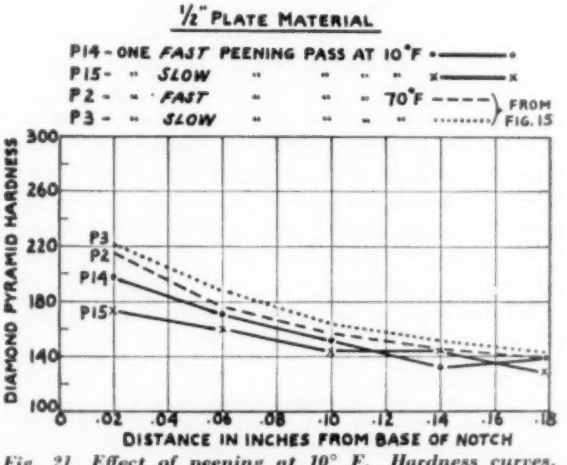
½" PLATE MATERIAL
P14 - ONE FAST PEENING PASS AT 10°F
P15 - " SLOW " " " "
P2 - " FAST " " " 70°F
P3 - " SLOW " " " "
FROM FIG. 15
DIAMOND PYRAMID HARDNESS
DISTANCE IN INCHES FROM BASE OF NOTCH

Fig. 21 Effect of peening at 10° F. Hardness curves. Prime plate

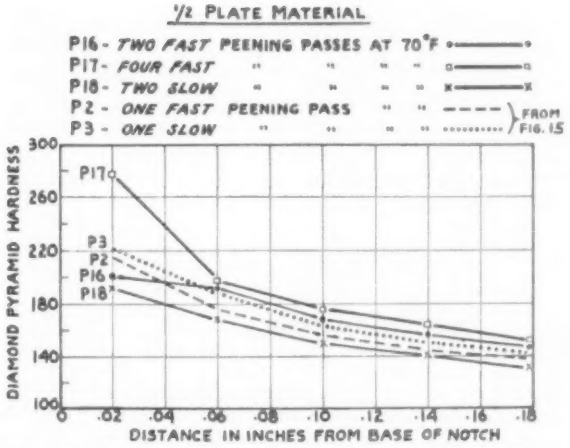
½ PLATE MATERIAL
P16 - TWO FAST PEENING PASSES AT 70°F
P17 - FOUR FAST " " " "
P18 - TWO SLOW " " " "
P2 - ONE FAST PEENING PASS " "
P3 - ONE SLOW " " " "
FROM FIG. 15
DIAMOND PYRAMID HARDNESS
DISTANCE IN INCHES FROM BASE OF NOTCH

Fig. 22 Effect of multiple peening passes. Hardness curves. Prime plate

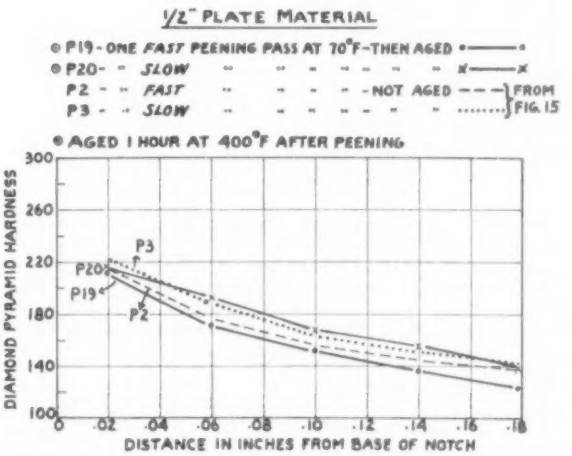
½" PLATE MATERIAL
P19 - ONE FAST PEENING PASS AT 70°F - THEN AGED
P20 - " SLOW " " " " " "
P2 - " FAST " " " - NOT AGED
P3 - " SLOW " " " " " "
FROM FIG. 15
AGED 1 HOUR AT 400°F AFTER PEENING
DIAMOND PYRAMID HARDNESS
DISTANCE IN INCHES FROM BASE OF NOTCH

Fig. 23 Effect of aging treatment after peening. Hardness curves. Prime plate

SAMPLE NUMBER	AMOUNT OF PEENING	PEENING TEMP.	AVERAGE DEPTH OF PEENED GROOVE	TRANSITION TEMP. AT 15 FT. LBS.	HARDNESS .020" BELOW NOTCH
P-1	NONE (MACHINED NOTCH)	—	—	-165°F	125
P-2	ONE FAST PEENING PASS	70°F	.050"	-150°F	217
P-4	" " " "	200°F	.055"	-100°F	208
P-6	" " " "	300°F	.064"	-135°F	222
P-8	" " " "	500°F	.056"	- 65°F	242
P10	" " " "	700°F	.066"	85°F	240
P12	" " " "	900°F	.074"	90°F	245
P14	" " " "	10°F	.043"	-130°F	198
P-3	ONE SLOW PEENING PASS	70°F	.073"	-70°F	221
P-5	" " " "	200°F	.086"	-75°F	215
P-7	" " " "	300°F	.070"	50°F	230
P-9	" " " "	500°F	.072"	160°F	275
P11	" " " "	700°F	.089"	150°F	252
P13	" " " "	900°F	.094"	125°F	295
P15	" " " "	10°F	.063"	-140°F	172
P16	TWO FAST PEENING PASSES	70°F	.060"	-125°F	203
P17	FOUR " " "	70°F	.078"	-70°F	277
P18	TWO SLOW " "	70°F	.120"	-60°F	192
P19	ONE FAST PEENING PASS - THEN AGED AT 400°F	70°F	.037"	-120°F	212
P20	ONE SLOW PEENING PASS - THEN AGED AT 400°F	70°F	.060"	-130°F	214

Fig. 24 Summary of prime plate test data

(*a*) The depths of the peened grooves tend to increase with increasing peening temperatures until a temperature of 500° F is reached for fast peening and 300° F for slow peening, where the depths of grooves decrease and then continue to increase with peening temperatures up to 900° F. This reversal is believed to be associated with peening the metal in the lower end of the so-called blue brittle range. It may also be noted that the shallowest depth of groove for each peening rate was obtained on the sample peened at 10° F.

(*b*) The lowest transition temperature (−165° F) was obtained on the unpeened sample having a machined notch. The transition temperatures are more adversely affected by the slow peening travel than by the fast, with the exception of the samples peened at 10° F. The transition temperatures show a sharp increase at the same points where the depths of notch decrease (500° F for fast and 300° F for slow peening) and they continue to be adversely affected up to 900° F. Although the results for peening at 10° F may have

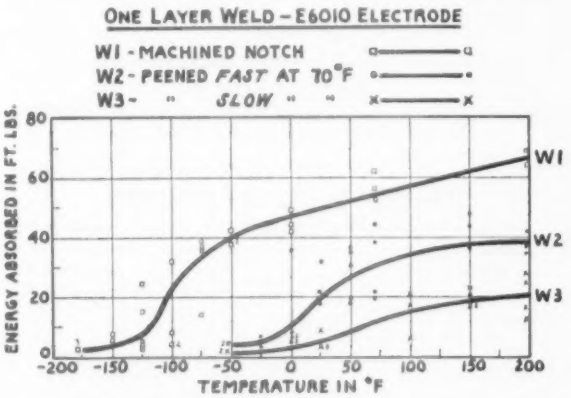

Fig. 25 Effect of peening a one-layer weld. Impact curves. Weld metal

no practical significance, it is interesting to note that the transition temperature is considerably lower for slow peening at 10° F than for slow peening at 70° F. Multiple peening passes at 70° F (samples P16, P17 and P18) have an adverse effect on the transition temperature with the fast travel rate; while there is very little difference (10°) between the transition temperatures of the samples peened with one slow vs. two slow passes. The effect of an aging treatment subsequent to peening was not consistent in that there was a slight increase in the transition temperature of the sample aged after fast peening (P19 vs. P2) and a marked decrease in the transition temperature of the sample aged after slow peening (P20 vs P3).

(c) As would be expected, the hardness 0.020 in. under the peened notch in all of the samples is considerably higher than the hardness under the machined notch in the unpeened sample (P1). The samples peened in the blue brittle temperature range have higher hardness than those peened at 70° F; while the samples peened at 10° F have a lower hardness than those peened at 70° F. There is a fair degree of correlation between the hardness and the transition temperatures; that is, higher hardness usually accompanies higher transition temperatures. This correlation, however, is not consistent enough to accurately predict from hardness readings the relative notch toughness of peened material.

IMPACT TESTS ON WELD METAL

After completing the tests just described on prime

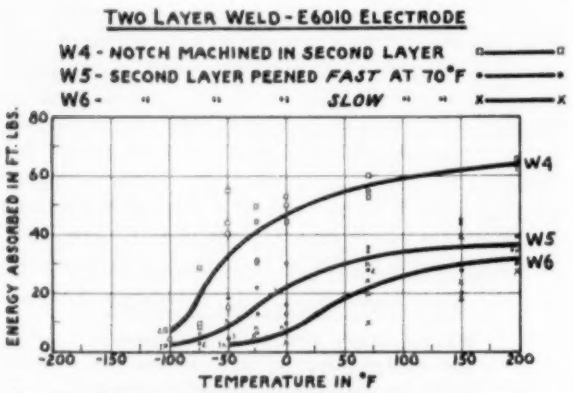
TWO LAYER WELD - E6010 ELECTRODE
W4 - NOTCH MACHINED IN SECOND LAYER
W5 - SECOND LAYER PEENED FAST AT 70°F
W6 - " " " SLOW " "
ENERGY ABSORBED IN FT. LBS.
TEMPERATURE IN °F
W4
W5
W6

Fig. 26 Effect of peening the second layer of a two-layer weld. Impact curves. Weld metal

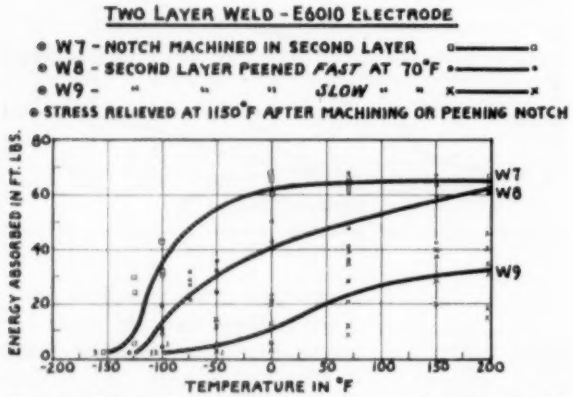
TWO LAYER WELD - E6010 ELECTRODE
W7 - NOTCH MACHINED IN SECOND LAYER
W8 - SECOND LAYER PEENED FAST AT 70°F
W9 - " " " SLOW " "
STRESS RELIEVED AT 1150°F AFTER MACHINING OR PEENING NOTCH
ENERGY ABSORBED IN FT. LBS.
TEMPERATURE IN °F
W7
W8
W9

Fig. 27 Effect of stress relieving after peening the second layer of a two-layer weld. Impact curves. Weld metal

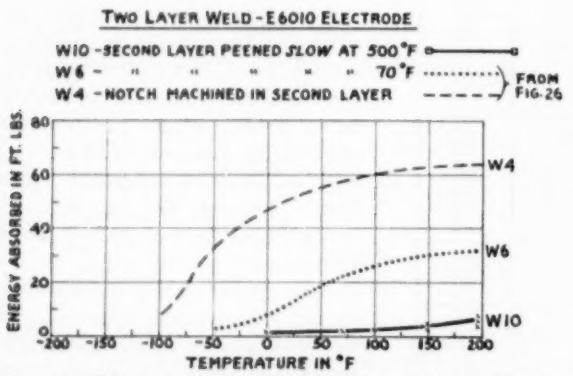
TWO LAYER WELD - E6010 ELECTRODE
W10 - SECOND LAYER PEENED SLOW AT 500°F
W6 - " " " " " 70°F
W4 - NOTCH MACHINED IN SECOND LAYER
FROM FIG. 26
ENERGY ABSORBED IN FT. LBS.
TEMPERATURE IN °F
W4
W6
W10

Fig. 28 Effect of peening weld metal at 500° F. Impact curves. Weld metal

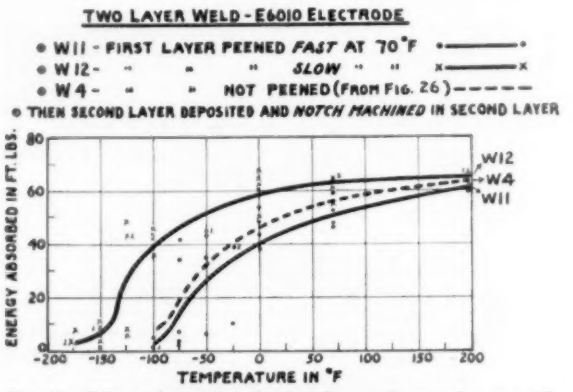
TWO LAYER WELD - E6010 ELECTRODE
W11 - FIRST LAYER PEENED FAST AT 70°F
W12 - " " " SLOW " "
W4 - " " NOT PEENED (FROM FIG. 26)
THEN SECOND LAYER DEPOSITED AND NOTCH MACHINED IN SECOND LAYER
ENERGY ABSORBED IN FT. LBS.
TEMPERATURE IN °F
W12
W4
W11

Fig. 29 Effect of peening the first layer of a two-layer weld. Impact curves. Weld metal

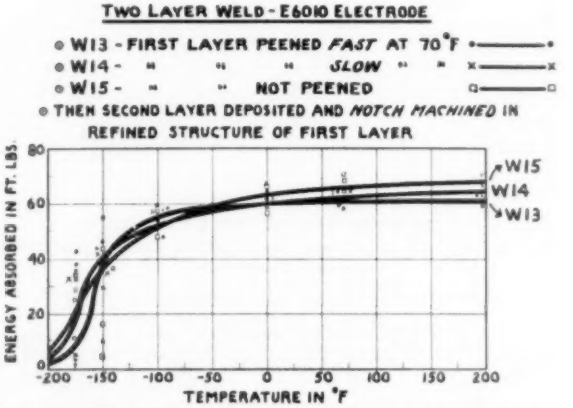
TWO LAYER WELD - E6010 ELECTRODE
W13 - FIRST LAYER PEENED FAST AT 70°F
W14 - " " " SLOW " "
W15 - " " NOT PEENED
THEN SECOND LAYER DEPOSITED AND NOTCH MACHINED IN REFINED STRUCTURE OF FIRST LAYER
ENERGY ABSORBED IN FT. LBS.
TEMPERATURE IN °F
W15
W14
W13

Fig. 30 Effect of a covering layer on restoring properties of peened weld metal. Impact curves. Weld metal

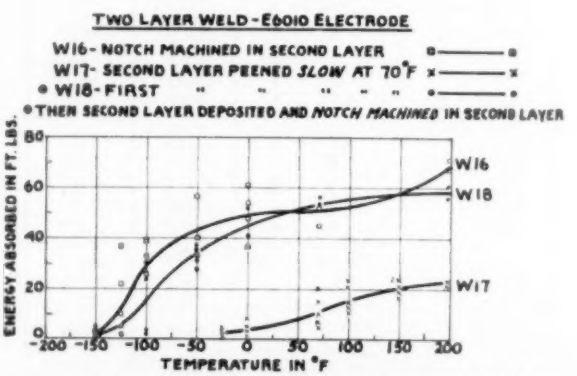
TWO LAYER WELD - E6010 ELECTRODE
W16 - NOTCH MACHINED IN SECOND LAYER
W17 - SECOND LAYER PEENED SLOW AT 70°F
W18 - FIRST " " " " "
THEN SECOND LAYER DEPOSITED AND NOTCH MACHINED IN SECOND LAYER
ENERGY ABSORBED IN FT. LBS.
TEMPERATURE IN °F
W16
W18
W17

Fig. 31 Effect of peening weld metal deposited in 1-in. thick plating. Impact curves. Weld metal

plating, the effect of peening on the notch toughness and hardness of weld metal was investigated, using several welding and peening variables. A preliminary study had indicated that peening the first weld layer in a standard 60-deg vee-butt joint was not practical with the automatic peening machine, since the weld metal was partially driven through the root of the joint with severe distortion of the root plate material. It was, therefore, decided to deposit the weld metal in a $^3/_8$-in. diam groove machined into the plate surface lengthwise along the centerline of a test plate 24 in. long by $2^1/_2$

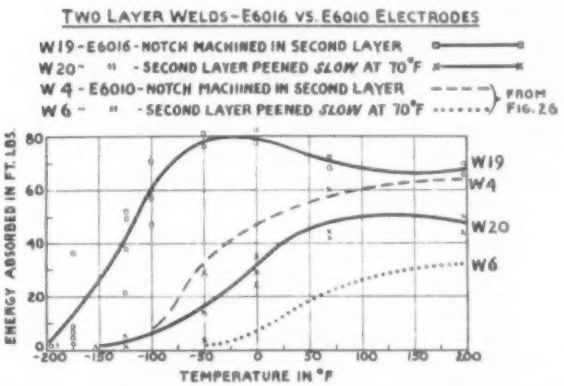
TWO LAYER WELDS - E6016 VS. E6010 ELECTRODES
W19 - E6016 - NOTCH MACHINED IN SECOND LAYER
W20 - " - SECOND LAYER PEENED SLOW AT 70°F
W4 - E6010 - NOTCH MACHINED IN SECOND LAYER
W6 - " - SECOND LAYER PEENED SLOW AT 70°F
FROM FIG. 26
ENERGY ABSORBED IN FT. LBS.
TEMPERATURE IN °F
W19
W4
W20
W6

Fig. 32 Effect of peening a low-hydrogen electrode weld. Impact curves. Weld metal

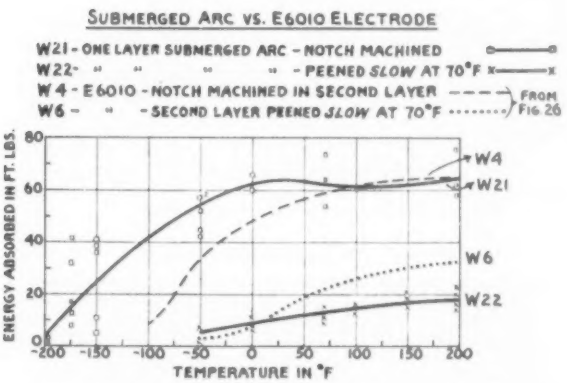
SUBMERGED ARC VS. E6010 ELECTRODE
W21 - ONE LAYER SUBMERGED ARC - NOTCH MACHINED
W22 - " " " " - PEENED SLOW AT 70°F
W4 - E6010 - NOTCH MACHINED IN SECOND LAYER
W6 - " - SECOND LAYER PEENED SLOW AT 70°F
FROM FIG. 26
ENERGY ABSORBED IN FT. LBS.
TEMPERATURE IN °F
W4
W21
W6
W22

Fig. 33 Effect of peening a submerged arc weld. Impact curves. Weld metal

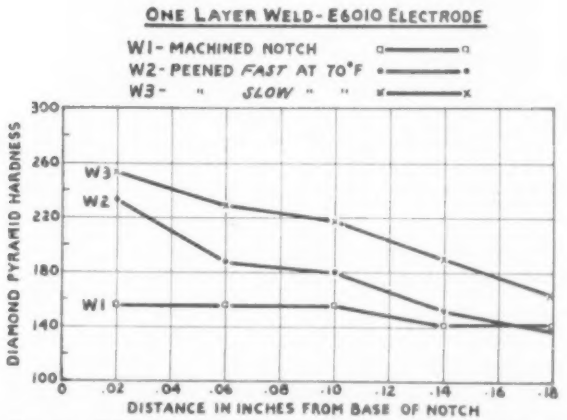

Fig. 34 Effect of peening a one-layer weld. Hardness curves. Weld metal

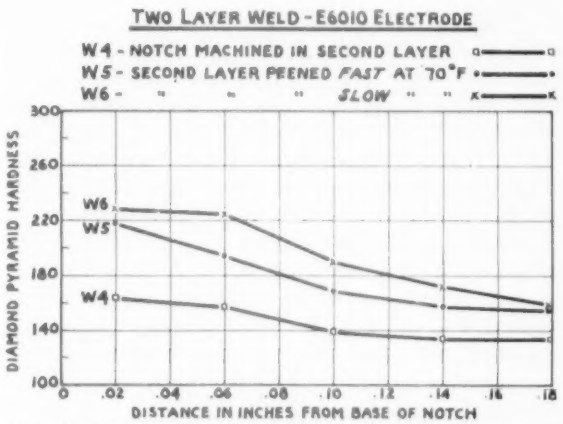
TWO LAYER WELD - E6010 ELECTRODE
W4 - NOTCH MACHINED IN SECOND LAYER
W5 - SECOND LAYER PEENED FAST AT 70°F
W6 - " " " SLOW " "
DIAMOND PYRAMID HARDNESS
DISTANCE IN INCHES FROM BASE OF NOTCH
W6
W5
W4

Fig. 35 Effect of peening the second layer of a two-layer weld. Hardness curves. Weld metal

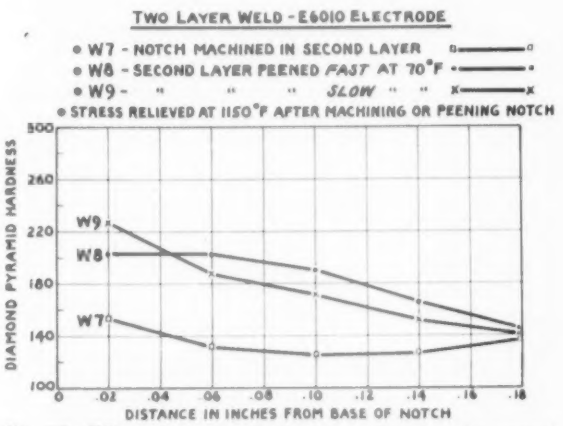
TWO LAYER WELD - E6010 ELECTRODE
W7 - NOTCH MACHINED IN SECOND LAYER
W8 - SECOND LAYER PEENED FAST AT 70°F
W9 - " " " SLOW " "
STRESS RELIEVED AT 1150°F AFTER MACHINING OR PEENING NOTCH
DIAMOND PYRAMID HARDNESS
DISTANCE IN INCHES FROM BASE OF NOTCH
W9
W8
W7

Fig. 36 Effect of stress relieving after peening the second layer of a two-layer weld. Hardness curves. Weld metal

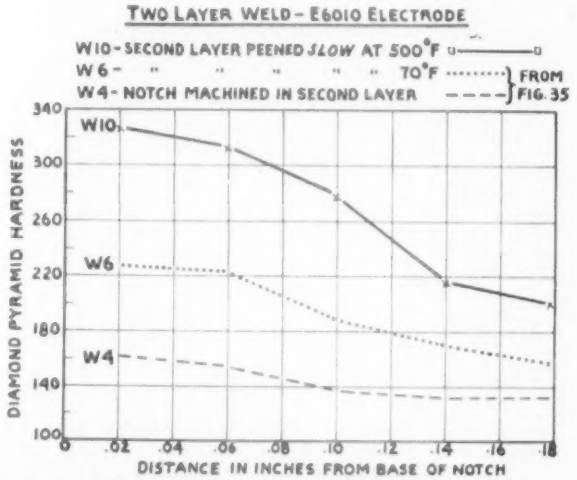
TWO LAYER WELD - E6010 ELECTRODE
W10 - SECOND LAYER PEENED SLOW AT 500°F
W6 - " " " " " 70°F
W4 - NOTCH MACHINED IN SECOND LAYER
FROM FIG. 35
DIAMOND PYRAMID HARDNESS
DISTANCE IN INCHES FROM BASE OF NOTCH
W10
W6
W4

Fig. 37 Effect of peening weld metal at 500° F. Hardness curves. Weld metal

in. wide. This welding groove was machined 0.150 in. deep for one-layer welds and 0.250 in. deep for two-layer welds. The plate thickness was $^1/_2$ in. for all samples except those shown in Figs. 31 and 33. All welding was done with the automatic stick feeder using $^5/_{32}$-in. diam electrodes, with the exception of two welds deposited by the submerged arc process (Fig. 33). The weld reinforcement was machined off flush with the plate surface prior to peening a notch or machining a notch lengthwise along the centerline of the weld. The peening on all of the weld metal samples was carried out with a single-peening pass, using the same chisel-shaped tool previously described. The conditions of hammer operation were the same as used on the prime plate samples; viz., the medium hammer at 90 psi air pressure and no riding load. Modified Charpy impact specimens of the same type previously described were then machined from these welded samples. All impact specimens were given a light etch to determine the amount of columnar structure or refined structure beneath the base of the notch. In the samples containing a machined notch, the base of the notch was located so that these samples had approximately the same average amount of columnar structure or refined structure behind the notch as the peened samples with which they were being compared.

The variables of welding, peening and notch location are described as follows in association with the impact test results shown in Figs. 25 to 33, inclusive:

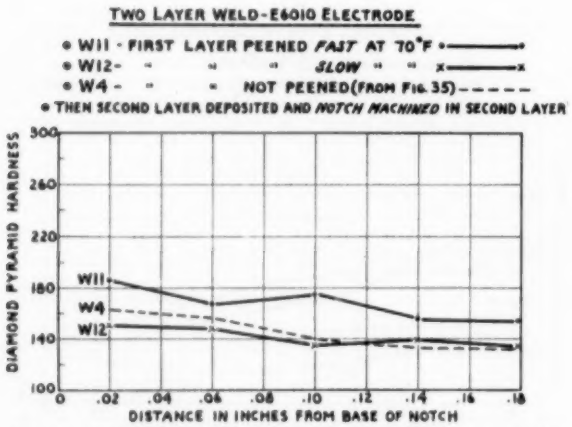
TWO LAYER WELD - E6010 ELECTRODE
W11 - FIRST LAYER PEENED FAST AT 70°F
W12 - " " " SLOW " "
W4 - " " NOT PEENED (FROM FIG. 35)
THEN SECOND LAYER DEPOSITED AND NOTCH MACHINED IN SECOND LAYER
DIAMOND PYRAMID HARDNESS
DISTANCE IN INCHES FROM BASE OF NOTCH

Fig. 38 Effect of peening the first layer of a two-layer weld. Hardness curves. Weld metal

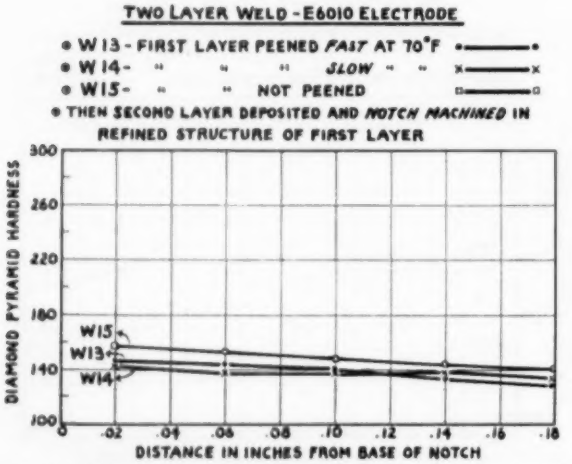
TWO LAYER WELD - E6010 ELECTRODE
W13 - FIRST LAYER PEENED FAST AT 70°F
W14 - " " " SLOW " "
W15 - " " NOT PEENED
THEN SECOND LAYER DEPOSITED AND NOTCH MACHINED IN REFINED STRUCTURE OF FIRST LAYER
DIAMOND PYRAMID HARDNESS
DISTANCE IN INCHES FROM BASE OF NOTCH

Fig. 39 Effect of a covering layer on restoring properties of peened weld metal. Hardness curves. Weld metal

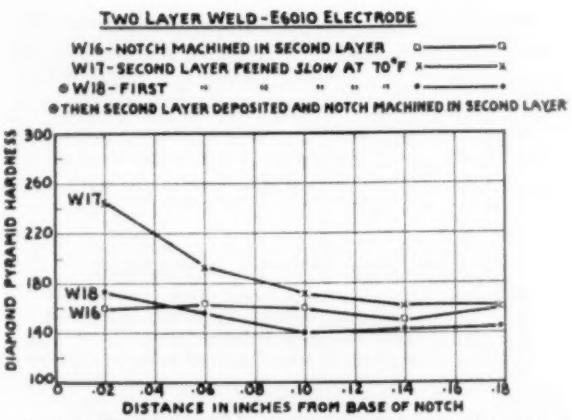
TWO LAYER WELD - E6010 ELECTRODE
W16 - NOTCH MACHINED IN SECOND LAYER
W17 - SECOND LAYER PEENED SLOW AT 70°F
W18 - FIRST " " " " "
THEN SECOND LAYER DEPOSITED AND NOTCH MACHINED IN SECOND LAYER
DIAMOND PYRAMID HARDNESS
DISTANCE IN INCHES FROM BASE OF NOTCH

Fig. 40 Effect of peening weld metal deposited in 1-in. thick plating. Hardness curves. Weld metal

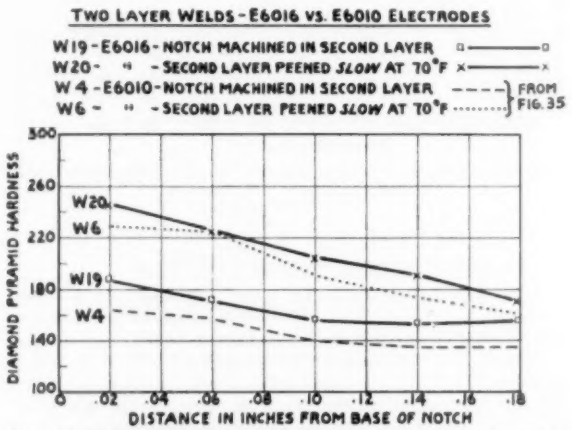
TWO LAYER WELDS - E6016 VS. E6010 ELECTRODES
W19 - E6016 - NOTCH MACHINED IN SECOND LAYER
W20 - " - SECOND LAYER PEENED SLOW AT 70°F
W4 - E6010 - NOTCH MACHINED IN SECOND LAYER
W6 - " - SECOND LAYER PEENED SLOW AT 70°F
FROM FIG. 35
DIAMOND PYRAMID HARDNESS
DISTANCE IN INCHES FROM BASE OF NOTCH

Fig. 41 Effect of peening a low-hydrogen electrode weld. Hardness curves. Weld metal

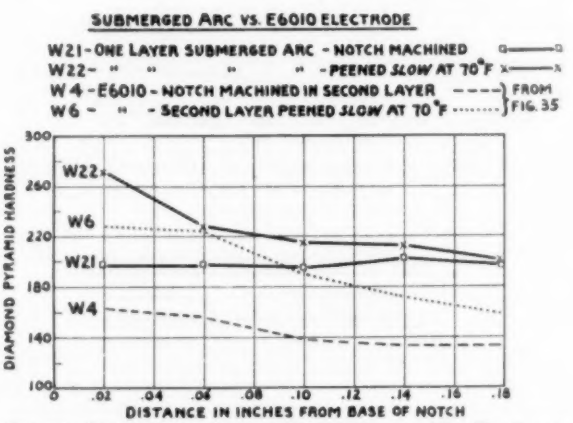
SUBMERGED ARC VS. E6010 ELECTRODE
W21 - ONE LAYER SUBMERGED ARC - NOTCH MACHINED
W22 - " " " " - PEENED SLOW AT 70°F
W4 - E6010 - NOTCH MACHINED IN SECOND LAYER
W6 - " - SECOND LAYER PEENED SLOW AT 70°F
FROM FIG. 35
DIAMOND PYRAMID HARDNESS
DISTANCE IN INCHES FROM BASE OF NOTCH

Fig. 42 Effect of peening a submerged arc weld. Hardness curves. Weld metal

SAMPLE NO.	FIG.	PLATE GAUGE	ELECTRODE	NO. LAYERS	PARTICULARS OF WELDING AND PEENING	AVERAGE DEPTH OF PEENED GROOVE	TRANSITION TEMP. AT 15 FT. LBS.	HARDNESS .020" BELOW NOTCH
W1	25	1/2"	E6010	1	NOTCH MACHINED.	----	-110°F	196
W2	"	"	"	"	NOTCH PEENED FAST.	.039"	15°F	274
W3	"	"	"	"	NOTCH PEENED SLOW.	.052"	100°F	254
W4	26	1/2"	E6010	2	NOTCH MACHINED IN 2nd LAYER.	----	- 80°F	184
W5	"	"	"	"	NOTCH PEENED FAST IN 2nd LAYER.	.042"	- 25°F	219
W6	"	"	"	"	NOTCH PEENED SLOW IN 2nd LAYER.	.056"	35°F	229
W7	27	1/2"	E6010	2	SAME AS W4 BUT S.R.* AFTER MACHINING.	----	-120°F	156
W8	"	"	"	"	SAME AS W5 BUT S.R.* AFTER PEENING.	.040"	- 90°F	203
W9	"	"	"	"	SAME AS W6 BUT S.R.* AFTER PEENING.	.052"	25°F	227
W10	28	1/2"	E6010	2	NOTCH PEENED SLOW AT 500°F IN 2nd LAYER.	.054"	ABOVE 200°F	329
W11	29	1/2"	E6010	2	1st LAYER PEENED FAST - NOTCH MACHINED IN 2nd LAYER	----	- 75°F	187
W12	"	"	"	"	1st LAYER PEENED SLOW - NOTCH MACHINED IN 2nd LAYER.	----	-135°F	151
W13	30	1/2"	E6010	2	1st LAYER PEENED FAST - 2nd LAYER DEPOSITED AND NOTCH MACHINED IN REFINED STRUCTURE OF 1st LAYER.	----	-165°F	158
W14	"	"	"	"	1st LAYER PEENED SLOW - 2nd LAYER DEPOSITED AND NOTCH MACHINED IN REFINED STRUCTURE OF 1st LAYER.	----	-175°F	147
W15	"	"	"	"	1st LAYER NOT PEENED - 2nd LAYER DEPOSITED AND NOTCH MACHINED IN REFINED STRUCTURE OF 1st LAYER.	----	-185°F	166
W16	31	1"	E6010	2	NOTCH MACHINED IN 2nd LAYER.	----	-120°F	160
W17	"	"	"	"	NOTCH PEENED SLOW IN 2nd LAYER.	.050"	100°F	244
W18	"	"	"	"	1st LAYER PEENED SLOW - NOTCH MACHINED In 2nd LAYER	----	-160°F	171
W19	32	1/2"	E6016	2	NOTCH MACHINED IN 2nd LAYER.	----	-170°F	188
W20	"	"	"	"	NOTCH PEENED SLOW IN 2nd LAYER.	.045"	- 55°F	244
W21	33	1"	SUBMERGED ARC	1	NOTCH MACHINED.	----	-175°F	197
W22	"	"	"	"	NOTCH PEENED SLOW.	.037"	100°F	271

NOTES: ALL PEENING CARRIED OUT AT 70°F EXCEPT ON SAMPLE W10
* S.R. - STRESS RELIEVED AT 1150°F FOR 1 HOUR.

Fig. 43 Summary of weld metal test data

Figure 25 shows the effect of peening at 70° F a one-layer weld deposited with an E6010 electrode. With both fast peening (W2) and slow peening (W3) there is considerable loss in energy absorption and increase in the transition temperature as compared with the unpeened sample (W1) containing a machined notch.

Figure 26 shows the effect of peening at 70° F the top or second layer of a two-layer E6010 weld. It is obvious that both fast peening (W5) and slow peening (W6) of the top layer have a pronounced adverse effect on the notch toughness as compared with the sample (W4) containing a machined notch. The base of the notches in these three samples was in the columnar structure of the second weld layer.

Figure 27 shows the effect of stress relieving for 1 hr at 1150° F after peening the top layer of a two-layer E6010 weld. These specimens are identical with those shown in Fig. 26 with the exception of the stress-relieving treatment. Comparison of the results shown in Figs. 26 and 27 indicate that the stress-relieving treatment improved the impact properties of the sample peened fast (W8 vs. W5) but had practically no effect on the sample peened slow (W9 vs. W6). These results indicate that stress relieving at 1150° F after peening cannot be relied upon to restore peened weld metal to its original notch toughness.

Figure 28 shows the effect of peening E6010 weld metal at an elevated temperature of 500° F, using only the slow rate of peening travel. This test was made to verify the trends already shown in Fig. 9 for peening prime plating at 500° F. The curves W4 and W6 from Fig. 26 have been replotted on Fig. 28 for comparison purposes and it is obvious that peening weld metal at 500° F results in a much more drastic loss in notch toughness than peening at 70° F. In this respect the trend is similar to that found for prime plating peened at 500° F.

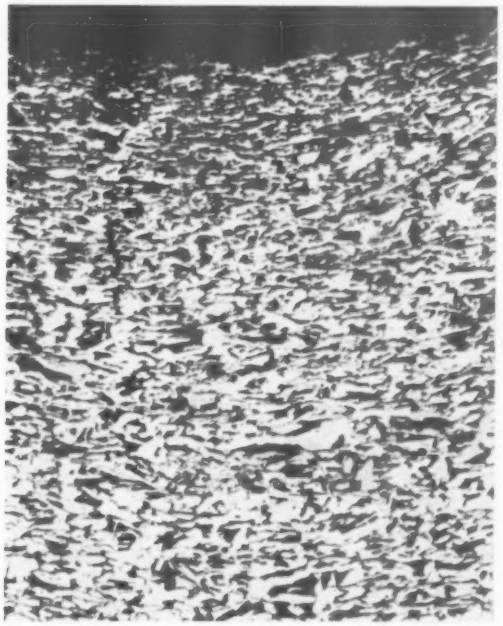

Fig. 44 Photomicrograph beneath notch in prime plate peened fast at 70° F. 100 ×

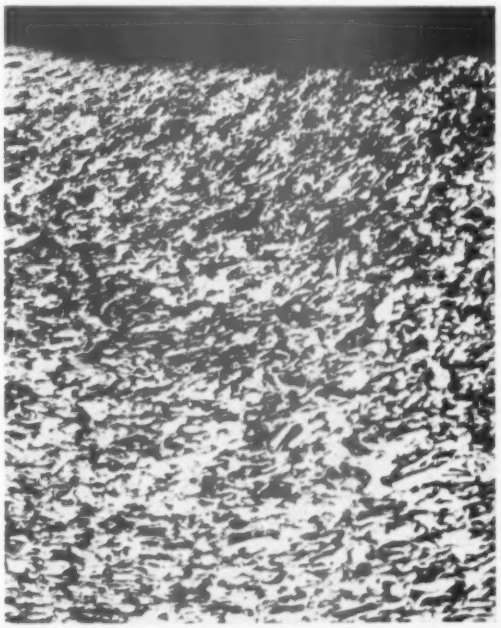

Fig. 45 Photomicrograph beneath notch in prime plate peened slow at 70° F. 100 ×

Figure 29 shows the effect of peening at 70° F the first layer of a two-layer E6010 weld. After peening the first weld layer fast in sample W11 and slow in sample W12, a second or covering weld layer was then deposited and notches were machined in the columnar structure of the second layer in each sample. The curve for sample W4, in which the first weld layer received no peening, is also shown in Fig. 29 for comparison. These results indicate that the notch toughness of the two-layer weld deposit was not adversely affected by peening the first layer.

Figure 30 shows the effect of a covering layer on restoring the impact properties of peened E6010 weld metal. These tests are similar to those shown in Fig. 29 except that the machined notches in the impact specimens are located in the refined structure of the first weld layer rather than in the columnar structure of the second layer. The energy absorption and transition temperature of samples W13, W14 and W15 are almost identical and the conclusion can be drawn from these results, together with the results shown in Fig. 29, that the adverse effects on notch toughness due to peening a weld layer will be eliminated by a subsequent covering layer. In this respect, it is felt that similar results would be obtained with any multiple-pass weld regardless of the type of electrode used.

Figure 31 shows the effect of peening E6010 weld metal deposited in a 1-in. thick plate rather than in $^1/_2$-in. plating. Sample W16 received no peening and has a notch machined in the columnar structure of the second layer; in sample W17, a notch was peened slow at 70° F in the second layer; and in sample W18, a notch was machined in the second layer after peening the first layer slow at 70° F. The results show that peening of the top weld layer has a pronounced adverse effect on notch toughness (W16 vs. W17) and that the notch toughness of a two-layer weld deposit is not seriously affected by peening the first layer (W16 vs. W18). These results show the same general trends as were found for weld metal deposited in $^1/_2$-in. plating, although the actual 15 ft-lb transition temperatures are somewhat different.

Figure 32 shows the effect of peening at 70° F weld metal deposited with a low-hydrogen electrode, type E6016, using the slow rate of peening travel (W20) as compared with unpeened weld metal containing a machined notch (W19). The curves W4 and W6 for an E6010 weld are also shown on Fig. 32 for comparison purposes. A considerable loss in notch toughness has resulted from peening the low-hydrogen weld (W19 vs. W20). It is also obvious that the unpeened low-hydrogen weld (W19) has much better impact properties than the unpeened E6010 weld (W4); also, that the peened low-hydrogen weld has better impact properties than the peened E6010 weld (W20 vs. W6), when peening was carried out at 70° F.

Figure 33 shows the effect of peening a one-layer weld made by the submerged arc process. This weld was made on 1-in. thick plating with the depth of the weld about $^3/_8$ in. Sample W21 was not peened and has a machined notch, while sample W22 has a notch produced by slow peening at 70° F. The two curves, W4 and W6, for an E6010 weld are also shown in Fig. 33 for comparison. The notch toughness of the peened submerged arc weld (W22) is slightly less than the peened E6010 weld (W6). In the unpeened condition, the submerged arc weld (W21) has better impact properties than the E6010 weld (W4).

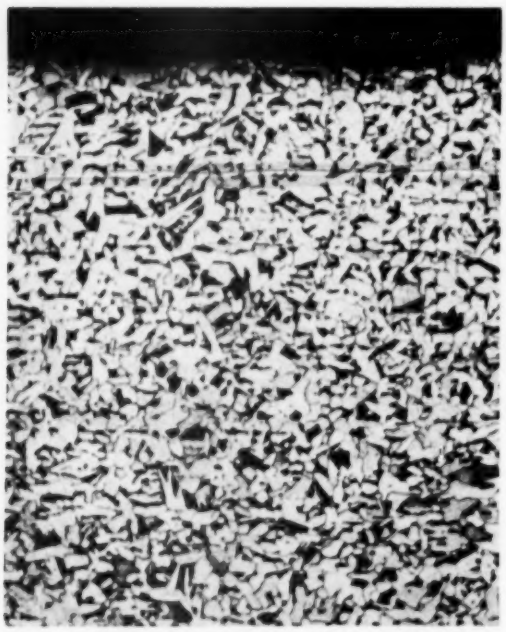

Fig. 46 Photomicrograph beneath milled notch in prime plate not peened. 100 ×

Fig. 47 Photomicrograph beneath notch in top layer of E6010 weld peened fast at 70° F. 100 ×

HARDNESS TESTS ON WELD METAL

Diamond Pyramid Hardness tests using a 5000-g load were made on an unbroken impact specimen from each of the 22 weld samples in the same manner as carried out on the prime plating. A row of indentations was made extending from 0.02 in. below the base of each peened or machined notch to the back of the specimen with a spacing of 0.04 in. between indentations. The results of these hardness tests on weld metal are shown in Figs. 34 to 42, inclusive.

SUMMARY OF WELD METAL TEST DATA

A summary of all the data obtained from the tests on weld metal is given in Fig. 43 which shows the average depth of the peened grooves, the transition temperature based on 15 ft-lb energy absorption and the hardness at a point 0.020 in. under the base of the notch. From this table the following observations can be made:

(*a*) The depths of the peened grooves in the weld metal samples are somewhat shallower than was obtained in prime plating peened under corresponding conditions, due to the higher hardness of the deposited weld metal. The low-hydrogen E6016 weld and the submerged arc weld have shallower grooves than the E6010 weld metal due to their higher hardness.

(*b*) A summary of the impact test results has already been given in the foregoing description of Figs. 25 to 33, inclusive.

(*c*) As in the case of prime plating, the peening of weld metal resulted in a marked increase in hardness beneath the base of the peened notch. The highest hardness (325 DPH), as well as the highest transition temperature (above 200° F), was found in the E6010 weld that was peened slow at 500° F. There appears to be no consistent relationship between hardness and transition temperature due in part, at least, to the use of different type electrodes and to the location of notches in different structures of the welds.

MICROSCOPIC EXAMINATION

A very limited microscopic examination was made on most of the samples covered by this investigation, and only a few typical photomicrographs were taken for inclusion in this report. As would be expected, there was considerable grain distortion resulting from the peening operation and the severity and depth of this deformation was more pronounced with the slow peening travel than with the fast (Figs. 44 to 49, incl.). In the prime plate samples, the sulfide inclusions were bent and the silicate inclusions were fragmented in the metal under the peened notches (Figs. 50 to 52 incl). When peening was carried out at temperatures of 500 to 900° F, numerous occluded or entrapped oxides and some microcracks were found at the base of the peened notches (Fig. 53). It is believed that these microcracks are associated with working the metal in the blue brittle temperature range.

DIMENSIONAL CHANGES DUE TO PEENING

In order to obtain some information on the magnitude and direction of the dimensional changes that may result from peening, suitable reamed bench marks were laid out on both surfaces of a prime plate test sample, 18 x 8 x $^1/_2$ in., and the dimensions between these bench marks before and after peening were measured to the nearest 0.0001 in. with a 2-in. Whittemore Strain Gage. There were four rows of bench marks across the width

Fig. 48 Photomicrograph beneath notch in top layer of E6010 weld peened slow at 70° F. 100 ×

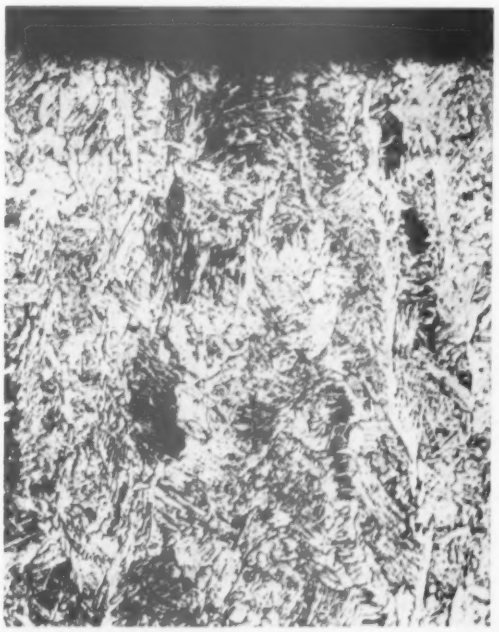

Fig. 49 Photomicrograph beneath milled notch in top layer of E6010 weld not peened. 100 ×

Fig. 50 Photomicrograph of bent sulfide in peened prime plate. 1000 ×

Fig. 51 Photomicrograph of fragmented silicate in peened prime plate. 1000 ×

Fig. 52 Photomicrograph of normal sulfide (bottom) and silicate (top) in unpeened prime plate. 1000 ×

Fig. 53 Photomicrograph of oxides and microcrack at base of notch in prime plate peened slow at 500° F. 1000 ×

of the test plate, each row being 2 in. apart, and there were eight bench marks 2 in. apart in each row, so that the changes in both width and length due to peening could be measured.

Peening was carried out with the same chisel-shaped tool as had been used for peening the impact samples previously described. The same conditions of hammer operation were also used; that is, the medium hammer at 90 psi air pressure, and no riding load. The fast travel rate (20 ipm) was used with the length of the tool nose parallel to the direction of travel.

The test plate was clamped to the top of the work table and a peening pass was made in the direction longitudinal to the length of the plate and at mid-width between the two central rows of bench marks. The length of the peened groove was 12 in.; 3 in. at

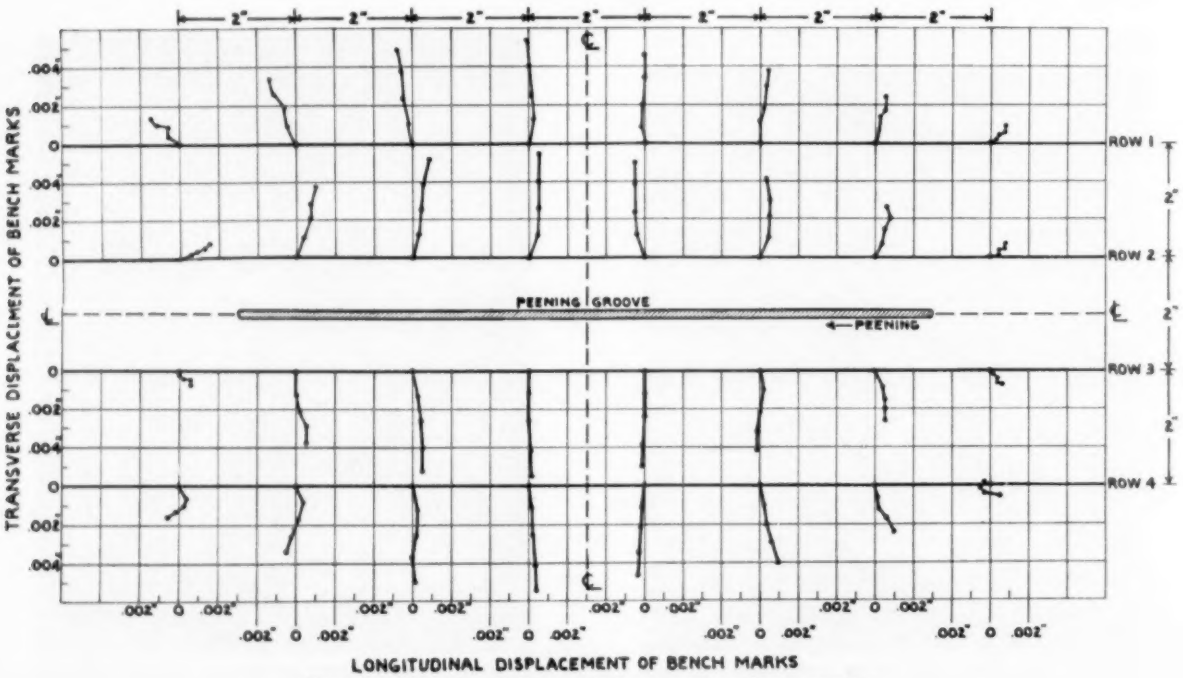

Fig. 54 Dimensional changes in front surface due to peening

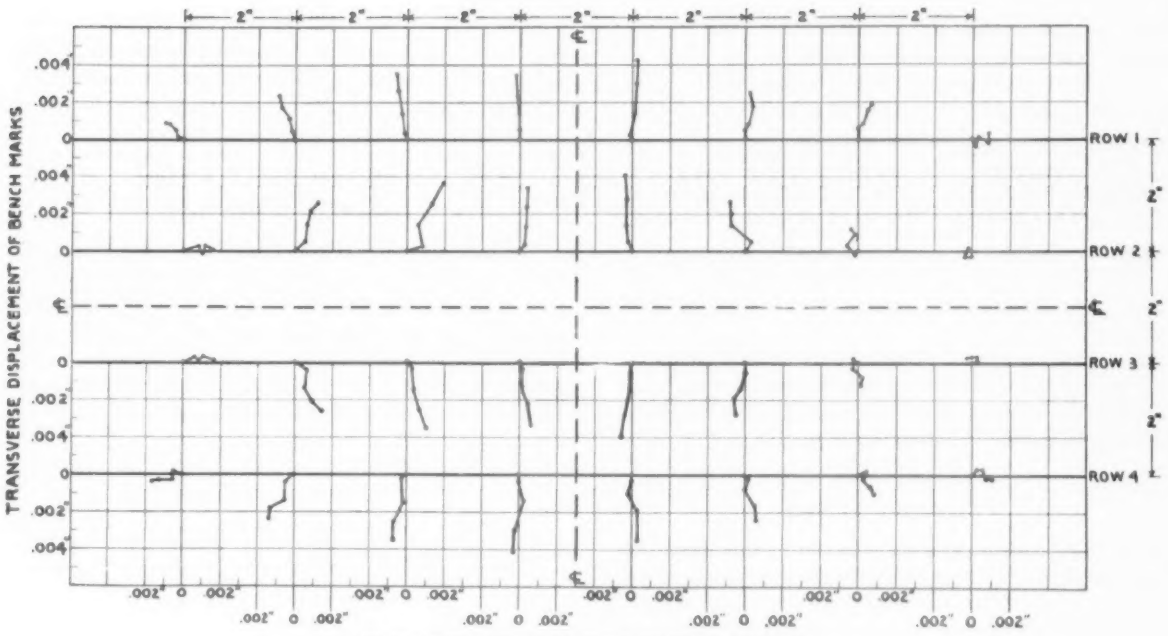

Fig. 55 Dimensional changes in back surface due to peening

each end of the plate being unpeened. Strain gage measurements were then taken, as had been done prior to peening, between the bench marks in each row and across each row on both the front and back surfaces of the plate; the front surface being the one that was peened. A second, third and fourth peening pass was then made in the previously peened groove and measurements taken after each pass.

The data obtained from these strain gage measurements are shown graphically in Figs. 54 and 55, which show the displacements in the width and length directions of the bench marks from their original positions. The four dots in way of each bench mark represent the successive total displacements after one, two, three and four peening passes. For each pair of bench marks spanning the width and length centerlines, it was assumed that each point moved an equal distance toward or away from the centerline due to the peening operation. The displacements of the remaining bench marks were determined by algebraically summing the movements of the points on each side of the centerlines.

A study of the results shown in Figs. 54 and 55 indicate that the greatest dimensional changes in width on both the front and back surfaces occurred between rows 2 and 3 spanning the peened groove. There was a marked increase in the total dimensional changes after each succeeding peening pass; the maximum change in width occurring at about mid-length of the peened groove after the fourth peening pass. It can also be seen that the net result of the four peening passes was to compress the length of the test plate along rows 2 and 3 spanning the peened groove and to elongate the plate along rows 1 and 4.

The magnitude of the dimensional changes would, of course, vary with different operating conditions or peening tools of different accuity.

GENERAL SUMMARY

1. The special peening machine developed for and used in this investigation insured reasonable duplication of the peening process for a given set of operating conditions.

2. Calibration of the pneumatic peening hammers indicated that their frequency in blows per minute increased with higher air pressures but was not appreciably affected by the riding load. The energy per blow generally tended to increase with higher air pressures and with heavier riding loads.

3. The chisel-shaped peening tool used in this investigation produced a natural peened notch which was used as the notch in modified Charpy impact specimens.

4. Tests on prime plating showed that the impact properties were adversely affected by peening. The greatest loss in notch toughness occurred when peening was carried out in the range of 500 to 900° F and this effect is believed to be associated with working the metal in the blue brittle temperature range.

5. The notch toughness of prime plating peened at 10° F approached that obtained on unpeened material.

6. Tests on deposited E6010 weld metal showed that peening of the last weld layer resulted in a pronounced loss in notch toughness. As in the case of prime plating, this effect was intensified by peening weld metal in the blue brittle range and by more drastic peening.

7. The low-hydrogen E6016 weld had much better

notch toughness than the E6010 weld in both the unpeened condition and as peened at 70° F.

8. The submerged arc weld compared favorably in notch toughness with the E6010 weld in both the unpeened condition and as peened at 70° F.

9. A stress-relieving treatment at 1150° F partly eliminated the adverse effects of mild peening on an E6010 weld but it had very little effect when the peening was more drastic.

10. The adverse effects of peening an E6010 weld layer were eliminated by a subsequent covering weld deposit.

11. The peening of prime plating or weld metal resulted in a pronounced increase in hardness and this increase was more severe when peening was carried out in the blue brittle temperature range.

FURTHER TESTS

The only additional work planned in this investigation is explosion bulge test transition temperature studies on completely welded joints of 1-in. thick plating in the as-peened vs. unpeened conditions. The preparation of these explosion test samples is presently in progress and the results obtained will be reported on in a later issue of THE WELDING JOURNAL.

ACKNOWLEDGMENT

The authors wish to express their sincere appreciation to all who have contributed their time, effort and advice in developing and carrying out this investigation, especially to the following members of the Peening Committee of the Welding Research Council: L. C. Bibber, *Chairman*, D. P. Brown, W. B. Bunn, C. E. Jackson, R. D. Stout and W. Spraragen.

References

1. De Garmo, E. P., Jonassen, F., and Meriam, J. L., "The Effect of Peening upon Residual Welding Stresses," THE WELDING JOURNAL, **25** (10), Research Suppl., 616-s to 623-s (1946).
2. Morris, J. L., "Extent of Peening Weld Deposits for Stress Relief," *Ibid.*, **27** (3), Research Suppl., 148-s to 158-s (1948).

Sandblasting and Annealing to Improve Flame-Cut High-Tensile Steel

by A. Erker

SMOOTH flame-cut surfaces using acetylene or city gas and a cutting machine were not difficult to secure at speeds of 8 to 20 ipm in a heat-treated steel $^{13}/_{16}$ in. thick, containing 0.34 C, 0.33 Si, 0.78 Mn, 0.018 P, 0.020 S, 2.24 Cr and 0.19 V. The mechanical properties before flame cutting were: yield point = 164,000 psi, tensile strength = 175,000 psi, elongation in 5 diam = 17%, reduction of area = 57%, 350 to 380 Vickers hardness. At the higher cutting speeds the surfaces were a little concave. Molten metal adhered to the lower edge of the cut below 8 ipm.

Tensile strength and ductility after flame cutting were determined on parallel section specimens 1 $^3/_{16}$ in. wide, 2 in. parallel length. The cutting speed was 11 $^1/_2$ ipm. A 110-ton axial stress fatigue machine was used. The peak tensile stress was 3.5 times the average tensile stress, consequently the range of stress from average to peak was 2.5 times the average stress. Fatigue limits are quoted as peak tensile stress for 2,000,000 cycles.

Hardness surveys showed 400–650 Vickers in the region $^1/_8$ in. below the cut surface. The following tensile strengths and reductions of area were obtained. (1) Machined edges: 175,000 psi, 37%. (2) Flame-cut edges: 169,000 psi, brittle fracture. (3) Sandblasted after cutting: 173,000 psi, brittle fracture. (4) Cut and stress relieved in an electric furnace 1 hr at 1040° F, air cooled: 163,000 psi, brittle fracture. (5) Same as No. 4 but with an additional 1 $^1/_2$ hr at 1080° F: 165,000 psi, brittle fracture despite the lowering of the surface hardness to 420 Vickers, maximum. (6) Torch annealed after cutting by moving a torch along each surface at such a speed that a red hot zone extended $^3/_{16}$ in. back of the cut. After one side was heated, it was allowed to cool in air before the other side was heated. The maximum hardness at the cut surface was 475 Vickers. The tensile strength was 159,000 psi with brittle fracture. (7) Torch annealed by two torches simultaneously, one on each side. The red hot zone close to the flame was $^3/_{16}$ in. deep. The fractures were brittle. (8) Finally, two

(*Continued on page 412-s*)

Abstract of "Festigkeitsversuche mit brenngeschnittenen Proben aus Cr-V Stahl," published in *Schweissen und Schneiden*, **5**, 183–189 (May 1953). Abstracted by Dr. G. E. Claussen.

The Incidence of Cracking in Welding Type 347 Steels

A survey of the nature and occurrence of the cracking difficulties which are being encountered in the welding of Type 347 steels

by L. K. Poole

Abstract

The major fabricators of stainless steels were visited to determine the nature and extent of cracking difficulties encountered in the welding of Type 347 steel. Out of the 23 fabricators all reported having seen crater cracks; 78%, hot short cracks or microfissuring; 39%, base metal cracks; 22%, cracks after stress relief and 13% have observed "star" cracks. Fully austenitic welds are most susceptible to cracks. Electrodes having a lime type coating and whose compositions are balanced to give at least 5% ferrite in non-dilution weld pads are least susceptible to microfissures and "star" and crater cracks. Differences of opinion exist as to the causes of base metal cracks and the various types of cracks observed after stress relief.

INTRODUCTION

TYPE 347 steel, because of its excellent properties in certain corrosive media and at elevated temperatures, has found wide usage in chemical and allied industries and in fields which require high strength at elevated temperatures.

The problem of depositing sound welds free from cracks and microfissures in the austenitic stainless steels has received a great deal of study in the past few years. In the more highly alloyed austenitic welds of the 310 and 330 types the crack sensitivity and tendency toward microfissuring has been substantially reduced by careful control of the carbon-to-silicon ratio;[1, 2, 7] however, the 0.08% maximum carbon limitation on Type 347 steel limits the practicability of using this means of controlling microfissuring, since it would present a serious production problem in producing core wire of the low-silicon content which is believed necessary to produce sound welds.

As an alternative, the metallurgist has continued to introduce ferrite in the microstructure to decrease crack susceptibility in Type 347 welds. This introduction of ferrite into the microstructure has, to a large extent, eliminated the cracking difficulties encountered in Type 347 welds, but it is by no means foolproof since it requires a very careful balance between the austenite- and ferrite-forming elements and is highly susceptible to dilution effects from the base metal, in which a higher nickel or lower chromium content is nearly always present. It has a further disadvantage in that the ferrite islands may, upon exposure to elevated temperatures, transform to sigma phase and render the weld deposit hard and brittle.[3, 4]

Prior to the start of work on a research program it was decided that a survey of industry be made to determine the nature and occurrence of the cracking difficulties which are being encountered in the welding of Type 347 steels. Although the objective of the present program is to study the influence of microstructure and composition on the properties of weld metal, the scope of the survey was broadened to include base metal cracking difficulties which have been reported on several occasions.

The survey was conducted by personal visits to various fabricators. Since the purpose of the survey was to determine the incidence of cracking, the survey was directed principally to fabricators rather than to investigators. This report is a summary of the information received during this survey together with some references to the literature.

The survey revealed that there are many unanswered problems in connection with the welding of Type 347 steels. These problems were discussed with the fabricators who offered opinions for the consideration of investigators who are studying some of these problems. A complete list of the companies and the individuals who were consulted is included at the end of the article.

The various types of cracking that have been observed at one time or another in the shops of the various fabricators visited during the course of the survey are given in Table 1 and are illustrated in Figs. 1 to 9. Very rigid welding controls and electrode specifications employed by some fabricators have brought some of these difficulties under reasonably satisfactory control, but the fundamental solution based on experimental facts and tested accordingly has not yet been found.

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Table 1—Types of Cracking Observed by Fabricators in the Welding of Type 347 Steels

Fabricator	*Crater*	*Star*	*Hot short or micro*	*Root*	*Base metal*	*Stress relief*
A	x	...	x	x	...	...
B	x	...	x	x	...	...
C	x	...	x	x	...	...
D	x	...	x	...	...	...
E	x	...	x	x	...	...
F	x	x	...	x	x	...
G	x	x	...	...	...	...
H	x	...	x	x	x	...
I	x	...	...	...	...	...
J	x	...	...	x	...	...
K	x	...	x	...	x	x
L	x	...	x	...	...	...
M	x	x	x	x	x	...
N	x	...	...	x	x	x
O	x	...	x	...	...	x
P	x	...	x	...	x	...
Q	x	...	x	...	...	...
R	x	...	x	...	x	...
S	x	...	x	...	...	...
T	x	...	x	...	...	...
U	x	...	x	...	x	x
V	x	...	x	x	...	...
W	x	...	x	...	x	x
%→	100	13	78	43	39	22

Weld Restraint

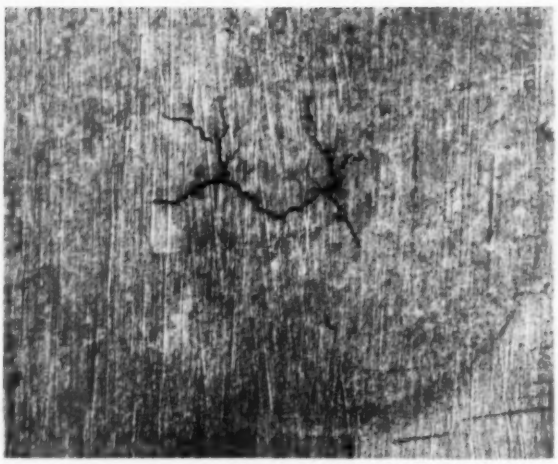
Weld metal cracking falls into several separate and distinct types which will be discussed separately. One factor which seems to be common to all types as indicated by the frequency of their occurrence is a function of the thickness of the section and the degree of restraint across the weld joint, heavier sections (about $^{3}/_{4}$ in. or over) and higher restraints showing increasing susceptibility to cracking.

Crater Cracks

By far the most common type of cracking occurs in the craters of Type 347 welds; these cracks are common to all types of welding methods and are now rarely seen in other than columbium bearing materials. This type of cracking is illustrated in Fig. 1 and is aptly described by Carpenter, Jessen and co-workers as follows:[5] "The cause, mode of formation, or for that matter any of the factors which influence the formation of these crater cracks, have not as yet been determined. These cracks are always intergranular and appear to result from the presence of an intergranular constituent in the microstructure, which does not, however, appear to be a slag constituent. Cracks appear regardless of whether the columbium is present in the base metal, the electrode, or both, and their size seems to be directly proportional to the amount of columbium present. Heliare welding and atomic hydrogen welding of the 19 Cr – 9 Ni materials stabilized with columbium also show crater cracking."

Courtesy, A. O. Smith Corp.

Fig. 1 Crater crack in root pass of Type 347 weld metal deposited in "U" groove in $^{3}/_{4}$-in. Type 304 base material. × 2



Courtesy, Public Service Electric and Gas Co.

Fig. 2. "Star cracks" in Type 347 weld metal. 7.5 ×

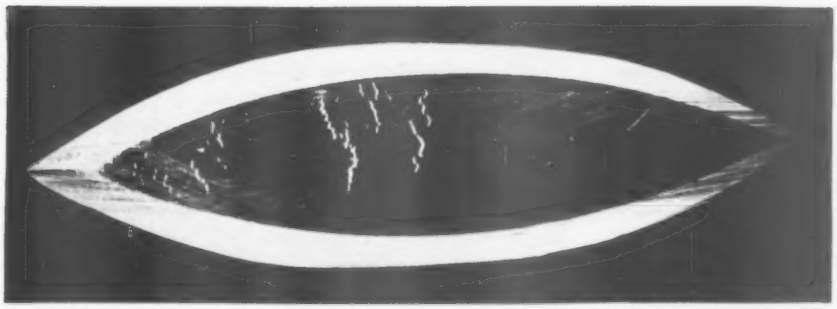
The frequency of crater cracks seems to decrease with increasing ferrite content and decreasing columbium content.

Star Cracks

"Star Cracks" are described as fine cracks generally $^{1}/_{16}$ to $^{3}/_{32}$ in. long radiating from a central point. These cracks, which are illustrated in Fig. 2, are seen on the face of welds which have been ground and also have been noted after service at elevated temperatures. The nature of these cracks indicates that they may be related in some way to crater cracking difficulties and one fabricator indicated a belief that they were caused by welding over craters in which the cracks had not been removed prior to the start of depositing the next layer of weld metal.

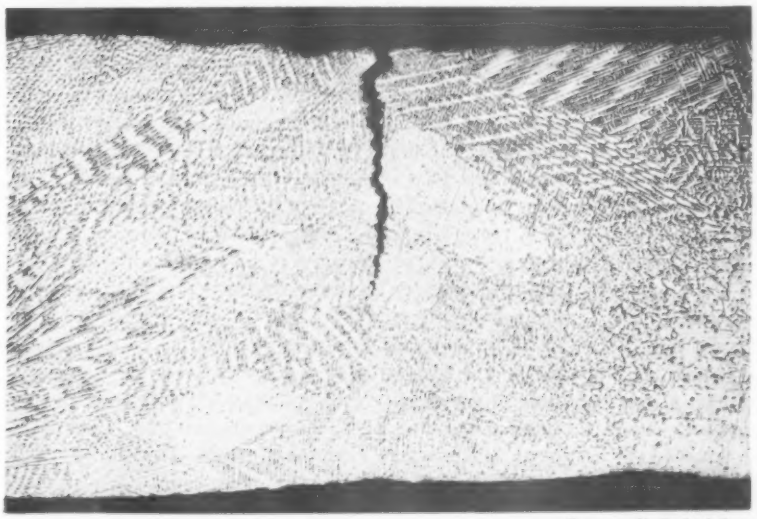
Hot Short and Microcracking

Hot short cracking and microfissuring occur in some cases even when ferrite is present in the microstructure.[6] Like crater cracks, the cause and method of formation of these cracks and fissures have not as yet received entirely satisfactory explanations. Micro segregations and intergranular films of a siliceous nature are believed by some to cause or at least to con-



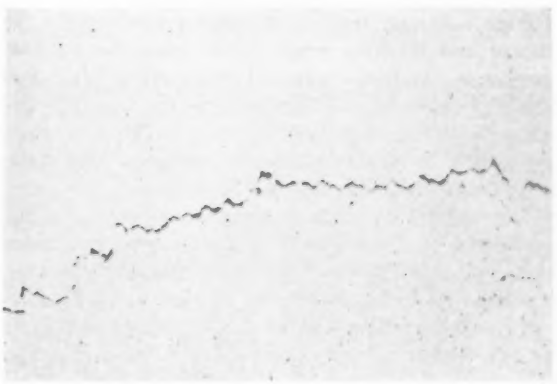
Courtesy, E. I. du Pont de Nemours and Co.

Fig. 3 Standard weld probe sample showing transverse hot short cracking approximately 3/8 in. below the surface of a 1 9/16-in. thick Type 347 weld. 1 ×. Unetched



Courtesy, U. S. Steel Corp

Fig. 4 Hot short type of weld metal cracking in 1/16-in. thick Type 347 sheet butt welded using the inert arc process and no added filler metal. 50 ×. Etched with Vilella's reagent



Courtesy, Electro Metallurgical Co.
a division of the Union Carbide & Carbon Corp.

Fig. 5 Microfissure in fully austenitic Type 347 weld deposit. 100 ×. Unetched

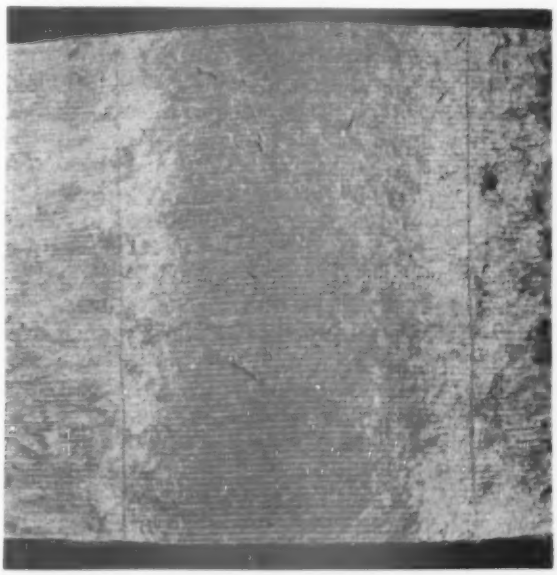
tribute to the formation of cracks of this nature. This type of cracking is reported to be aggravated by columbium additions and much discussion on this topic has appeared in the recent literature.[1, 2, 4–8]

The severity of this type of cracking varies considerably: it may be on a microscopic scale or be so severe as to necessitate complete rewelding. Several examples are shown in Figs. 3–5. When cracking is on a microscopic scale it very often escapes detection by nondestructive tests and is not revealed except by the opening up of tears or "fissures" in all-weld metal 0.505-in. tensile bars and bend tests (see Fig. 6).

In Type 347 steels the susceptibility to this type of cracking seems to be dependent on at least four factors, namely, (1) the magnitude of the stresses involved, (2) the type of electrode coating, (3) the effects of dilution and (4) microstructure.

Because of the many factors involved such as restraint, shrinkage, notches, joint design, section thickness, welding procedure, variations in section, electrode variations and welder's skill, it is impossible to predict the conditions under which the stress, when coupled with inherent weaknesses of the weld metal at very high temperatures, will result in the hot short or fissure type of cracking.

Fortunately, the metallurgist and the welding engineer have some measure of control over this type of



Courtesy, The Crane Co.

Fig. 6 Microcracks or fissures as revealed by the bend test. 2 1/2 ×

cracking. The use of lower welding currents has been found to reduce the tendency to form microcracks and fissures.[5] It also has been reported in the literature that, other factors being equal, the titania type coatings are more likely to produce cracks in susceptible alloys than the 100% lime type coatings.[2, 7, 8] This fact was confirmed by a large fabricator who, over the past several years, has run a large number of tests on electrodes of various manufacture and coating types. It was found in these tests that titania, when added to the coating even in small amounts, yielded weld deposits which contained more nonmetallic inclusions, were more susceptible to the formation of microfissures and were generally inferior in mechanical properties to the welds deposited using a lime type of coating containing no titania.

These facts are not to be construed to mean that the titania and lime-titania electrodes are unsatisfactory for all applications, since a large number of welds deposited by titania-bearing electrodes are giving satisfactory service in the field today. However, it is indicated that the lime type of electrodes which contain no titania will yield a weld deposit which is cleaner, has more uniform mechanical properties and which is the least sensitive to cracking.

A series of electrodes of varying Cb/C ratio was tested by another fabricator by depositing welds in a groove machined in a 1-in. cast Type 347 plate and welded in the 45-deg overhead position. Bend specimens made from these experimental electrodes showed that when the Cb/C ratio exceeded 7 and the ferrite fell below 4% the bends showed increasing tendency to fissure and failed before reaching the minimum requirements of the code.

Dilution Effects

To facilitate ease of rolling, forging and piercing operations, Type 347 base materials generally are prepared with a fully austenitic microstructure which is realized by the addition of nickel. Where large diameter electrodes and/or high welding currents are used, sufficient base metal dilution may occur to make the resulting weld deposit fully austenitic rather than partially ferritic. As a result the weld is subject to microcracking and fissuring difficulties accompanied by a severe reduction in strength and ductility.[5–7] This effect is most pronounced when welding on an alloy of higher nickel content and was aptly illustrated in a case where a fabricator, due to a mixup of base material, ran a series of welder's qualification tests using Type 310 base plate. The welds were fissured and the all-weld-metal 0.505-in. tensile bars showed elongations in the range of 4 to 6%. This same type of difficulty was also reported when inert arc welding Type 310 to Type 347 steel using Type 347 filler rod. An experimental dissimilar metal weld between Types 347 and $2^1/_4$ Cr tube material in which the groove on the side of the ferritic material had first been "buttered" with Type 310 weld metal also showed fine microcracks extending into fully austenitic areas in the Type 347 weld at the line of fusion of the "buttered" groove.

A related difficulty is one of heterogeneity in which partially ferritic and fully austenitic areas are seen in the same weld deposit, the latter areas showing fissures and microcracks. This difficulty is most prevalent when using large diameter electrodes and in submerged-arc multiple-pass welding, where cooling rates are slower and greater opportunity exists for segregations to occur.[4] There is also a question as to whether these heterogeneities might cause undesirable differences in thermal contraction which may result in cracking.

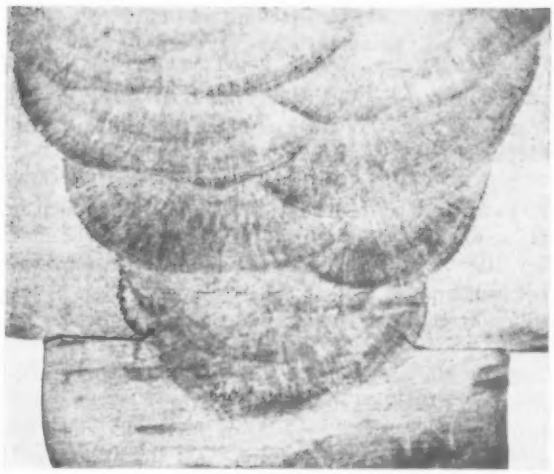
Fusion Line Cracks

Weld metal cracks originating at the line of fusion between weld and base metal appear to be of two types. The first type is associated with massive columbium carbide or low melting nonmetallic segregations in the base material adjacent to the fusion line. One opinion is that the heat of welding dissolves these carbides, or other nonmetallics, some of which are carried into the weld metal; upon solidification these carbides or nonmetallics are reprecipitated in an intergranular or interdendritic manner and open up into cracks as the result of cooling stresses. The second type is associated with an opening up of the grain boundaries of the parent metal in a location where no carbide or other segregations are apparent. No explanation was offered for this type of cracking based on experience with Type 347; however, similar experience with Timken 16-25-6 alloy indicated that this difficulty could be overcome by using smaller diameter electrodes. It was believed by this fabricator that this type of cracking could be explained on the following basis. On heating, the first portion of the plate material to dissolve would be the grain boundaries; it was reasoned, therefore, that if grain boundary melting occurred a notch would be formed and cracking would result from the welding stresses. Thus it was reasoned that a switch to smaller diameter electrodes which would require less heat input would overcome this difficulty. The fact that the switch to smaller electrodes overcame this difficulty tends to substantiate this hypothesis.

The belief that melting occurs first at the grain boundaries is substantiated by the dilatometer studies of Apblett and Pellini. In these studies dilations were measured on specimens heated by electrical resistance and incipient melting was reported to occur at the grain boundaries.[12]

Root Cracks

Root cracking, as illustrated in Figs. 7 and 8, has long been a problem particularly with the fabricator of pipe and tubing material. This type of cracking is not confined to the austenitic materials and is seen even in the welding of mild steels, particularly when a backing strip or ring is used. It was the opinion of one fabricator that the solution to this type of cracking could not



Courtesy, The Crane Co.

Fig. 7 Lower portion of weld made under full restraint in special 1-in. thick cast Type 347 plates showing root cracks formed at the junction of the back-up ring

be brought about by means of adjusting compositions or electrode coatings and that the solution would come as a result of change in joint design and/or welding technique which would eliminate the conventional metallic back-up ring thereby minimizing the stresses which are built up around the notch at the root of the weld. Several new methods of welding without the use of backing rings are in the development stage and show promise of overcoming the root cracking problem.

Tack welding of the backing ring, especially on the inside of the pipe to facilitate ease of fit-up, is reported to increase substantially the tendency of root cracks to form. This fabricator also reports that tapered backing rings are more prone to cracking than the flat type.

Careful fit-up, the use of small diameter electrodes and string bead technique in the root passes were recommended by nearly all fabricators as the best means of reducing the tendency of root cracks to form. Two fabricators also recommended the use of a 200–300° F preheat. It is their belief that when no preheat is used, the weld metal cools too rapidly to allow time for all of the slag to float to the top of the molten weld pool and as a result the stress from the notch together with intergranularly entrapped slag films will promote root cracking.

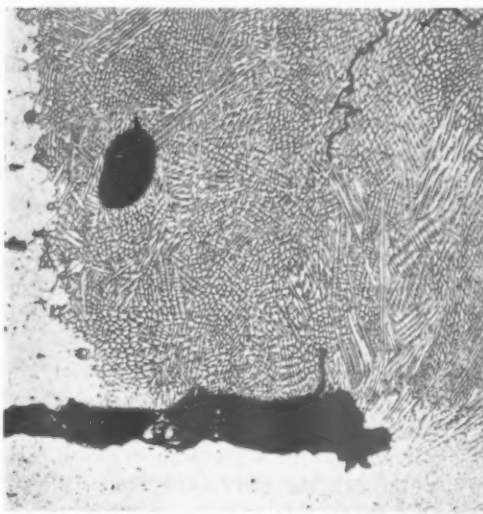
Because of the tendency to entrap slag in the root of welds and because of the better control of the weld pool and weld reinforcement, some fabricators are depositing the root pass using the inert arc method with added filler metal, and another without added filler metal. However, one of these fabricators cautions that care must be used in the selection of the filler metal used in order to compensate for the added dilution effects which result when using the inert arc method.

Base Metal Cracking

Base metal cracking although not nearly so common as weld metal cracking presents a serious problem since it occurs most often in sections whose thickness exceeds about $^3/_4$ in. where repairs are more difficult and costly.

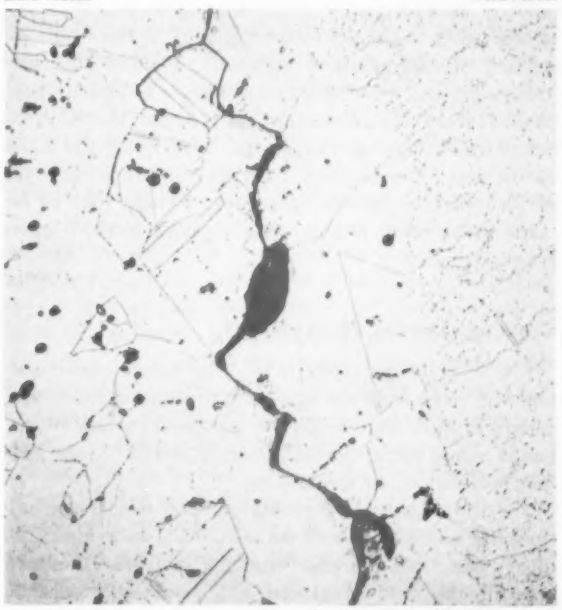
Base metal cracking usually occurs in the heat-affected zone and is for the most part intergranular. The cracks are usually but not always parallel to the line of fusion. An illustration is shown in Fig. 9. In this instance the crack was not apparent until after stress relief.

The mode of formation of these intergranular cracks in the heat-affected zone is unknown. In most cases



Courtesy, Knolls Atomic Power Laboratory

Fig. 8 Microfissures in low ferrite Type 347 weld deposit at junction of back-up ring. 100 ×. Oxalic acid etch



Courtesy, Electro Metallurgical Co., a division of the Union Carbide & Carbon Corp.

Fig. 9 Base metal cracking in heat-affected zone of Type 347 weld. 250 ×. Etched in Glyceregia

no carbides, nonmetallics or segregation of phases were seen in the microstructure. The intercrystalline nature of these cracks indicates that they are probably formed above the equicohesive temperature and under conditions of restraint.

In the case where carbide segregations were seen in base metal the crack propagated through the heat-affected zone principally in an intergranular manner and passed through areas in which columbium carbide segregations occurred. These carbides had apparently dissolved due to the heat of welding and reprecipitated in an intergranular eutectic-like fashion and apparently imparted an intergranular weakness at high temperature to the heat-affected zone.

One fabricator reported intergranular grain boundary cracks in base material starting at the line of fusion and extending about 2 to 4 grains into the base material.

The only theory advanced to explain these two types of cracking was that of grain boundary melting which was mentioned previously. This theory would not, however, explain the cracking which was seen in heavy coarse-grained forgings that were reported to occur at distances of $^1/_8$–$^3/_8$ in. from the fusion line and to propagate in a direction *normal* to the surface. In this case it was postulated that failure may have resulted from a grain boundary condition which permitted "grain slippage"; the reason for failure was not established.

The meager information available on the cause of base metal cracking will not permit the drawing of any conclusions as to the reason for the cracking. It is worthy to note, however, that the majority of cracking occurred in castings or forgings with grain sizes on the order of ASTM No. 2 or larger; the smallest grain size in which base metal cracking was reported was on the order of ASTM Nos. 4 or 5. One fabricator states a strong belief that base metal cracking is the result of welding on large-grained material. Further evidence to support the belief that grain size is a contributing factor is the report of one fabricator who welded a number of heavy forgings of the same type under the same conditions. Fine-grained forgings welded with little or no difficulty whereas numerous repairs had to be made as the result of base metal cracking in the coarse-grained forgings.

Cracking During Stress Relief

Cracking during stress relief, like base metal cracking, has come with the advent of heavier sections and occurs in both base materials and weld metals which, before stress relief, were apparently sound by the best means of nondestructive testing.

For the most part their nature and occurrence are the same as cracks which are seen in the as-welded condition, viz., intergranular cracking in ferrite depleted zones in the weld metal and in the heat-affected zone of the base material. However, one instance of transgranular cracking in base material was reported. In this case the crack was oriented normal to the line of fusion. The reason for cracking was not established; however, some ferrite stringers were noted in the base material. Ferrite stringers are known to affect hot rolling and forming operations but their effect, if any, on the weldability of these materials has not been established.

There is considerable speculation as to whether these cracks are formed during stress relief or were present in the as-welded condition. It is a generally accepted fact that very fine cracks cannot be detected by the best radiographic techniques, especially in view of the reduction in sensitivity as the material thickness increases.

One of the strongest indications that these cracks were formed before stress relief is the fact that their nature and location are similar to the cracks which are seen in the as-welded condition. On the other hand, it was pointed out that solution of ferrite may occur during stress relieving thus making the weld austenitic or nearly so and therefore susceptible to cracking under stress. This statement raises the question as to whether a weld which originally contained 6 to 8% ferrite would show sufficient solution of ferrite during stress relief to reduce the amount of this constituent below the critical amount necessary to assure sound welds, and further, would solution of ferrite in an already sound weld make it susceptible to cracking? Recent aging experiments involving standard 5–8% ferrite, low ferrite ($2^1/_2$%) and high-carbon high-nickel fully austenitic Type 347 electrodes indicate that after a 1950–2000° F (air-cooled) heat treatment the $2^1/_2$% ferrite weld deposit, in which most of the ferrite had gone into solution, may show superior properties when aged at embrittling temperatures.

It has been postulated that cracking during stress relief might be a stress rupture type of failure. To avoid excessive stresses due to thermal gradients in heavy sections, slow heating rates are usually specified and consequently the time during which a highly stressed weldment is at a given temperature may exceed the stress rupture life of the metal. At 1200° F the stress rupture curves for Type 347 weld metal are higher than for base material. From this standpoint it can be argued that the base metal should be expected to crack and thus provide sufficient relief of stress to prevent the cracking in the weld metal.

Arrested heating and cooling cycles have been tried with some success to minimize this condition but as yet the results are not conclusive. This method consists in heating to a temperature of 800–1000° F and holding for a period of time (usually about 2–4 hr) to relieve some of the residual stresses from welding. The furnace is then heated as rapidly as possible through the embrittling range (1000–1700° F) to the specified stress-relieving temperature. Cooling is rapid unless it is felt that distortion may be a problem, in which case rapid cooling through the embrittling range is used down to the 800–1000° F temperature where a holding time is again employed to reduce cooling stressed to a minimum.

One of the strongest points in favor of the embrittlement and stress rupture theories is that with one exception all cracking reported during stress relief occurred when heating and/or cooling rates were less than 200° F per hour, thus exposing the material to embrittling temperatures for a longer period of time. The one exception occurred in a large-grained forged base material after an 1850° F stress relief followed by rapid cooling.

Stress-relieving temperatures of 1150° F and below in accordance with Case 1107 of the ASME Boiler Code were reported to have been free from cracks under all conditions of heating and cooling rates. Doubt has been expressed as to whether stresses have been sufficiently relieved at these temperatures; however, it was reported in one case that adequate dimensional stability was achieved, and corrosion rates are better for a 950° F stress relief than for a 1550° F stress relief.

Those who seem to have the most experience report that when code or customer requirements for stress relieving require a temperature of 1350° F or over, it is necessary to employ temperatures of at least 1750° F in order to meet consistently the elongations required by the code. In one case it was reported that even 1750° F was not sufficient.

One fabricator who is welding thin ($^1/_{16}$-in.) sheets by Heliarc without filler metal reports that it is necessary to stress relieve at a temperature of at least 1950° F to obtain sufficient ductility to permit forming after welding. This temperature seems a little high in view of the fact that many welds in thin gage material have shown good forming characteristics after stress relieving at lower temperatures. This apparent discrepancy can probably be explained on a time-temperature basis since in the case cited the material was held at temperature only 3–5 min to reduce "sag" during stress relief. The forming characteristics may also be dependent on whether or not ferrite was present in the weld. Ferrite tends to inhibit microcracks which would open up during the forming operation. The condition under which ferrite may appear in these welds is explained later in the text.

It was noted that the cracking difficulties, especially after stress relieving, were reported more often in single-V or single-U grooves than in double-V or U grooves.

A literature report indicates that shrinkage stresses appear most severe in the root beads deposited in double-V joints.[7] This indicates that more statistical data will be needed to draw definite conclusions on crack susceptibility vs. joint type. Bishop & Bailey report that little difference was noted between the properties of welds deposited in single-U and single-V grooves.[12]

Welding Technique with Covered Electrodes

Most fabricators prefer to use $^3/_{32}$- or $^1/_8$-in. diameter electrodes and a string bead technique in the root pass, and some prefer to use this technique for the first 2 to 4 layers, since it is believed that this technique minimizes the tendency for root cracks to form, reduces the effects of dilution, the tendency for "hot short" type of cracking to occur and the tendency for slag entrapment and porosity. The use of the small diameter electrode also provides better control over the weld reinforcement and reduces "burn-through" in cases where no backup is used. As mentioned previously some fabricators prefer to use the inert arc method in the root passes for these reasons.

Because weaving or puddling may lead to porosity, slag entrapment and "hot shortness," some fabricators prefer to use string beads exclusively; most fabricators, however, feel that if weaving is limited to 2–3 times the electrode diameter in other than the root pass, no particular difficulty is encountered.

The use of a short arc is also recommended inasmuch as it helps to produce the cleanest welds and reduces the tendency to spatter, to form pinhole porosity, and decreases the loss of certain alloying elements across the arc.[9]

One fabricator recommends operating at the lowest practical welding currents consistent with good fusion since it has been his experience that high welding currents tend to promote "hot tears" and fissures and show lowered mechanical properties.[5]

When base metal cracking is encountered during welding one fabricator recommends the use of the cascade welding technique, which is a combined longitudinal and build-up sequence wherein weld beads are deposited in overlapping layers.[10] It is his opinion that this technique reduces the shrinkage across the joint thereby requiring less strength or yielding of the base material.

A variation of this technique called "four post welding" was reported to reduce base metal cracking in heavy pipe welds. This technique consists of building up pyramids or "posts" of weld metal in each of the four quadrants. The remainder of the weld is then deposited in stringer beads between the pyramids or "posts."

Another technique used with success in preventing base metal cracking in heavy materials consists of building up the sides of the weld joint with stringer beads as successive layers of weld are deposited. The success of this technique is attributed to the fact that the width of the weld joint is in effect narrowed, thereby decreasing the strain on the parent metal as the result of shrinkage across the weld. In addition it is felt that the stress distribution across the weld is more uniform, a condition which is believed desirable.

Because of the tendency to form root cracks all fabricators prefer to weld without the use of back-up strips or rings if at all possible; the preference is to weld the root on one side then back chip or grind and weld from the opposite side. When it is necessary to use a backing strip or ring the flat type is preferred for reasons previously discussed under root cracking.

When it is not permitted to use a back-up ring or

strip and the weld reinforcement is inaccessible after welding, it is sometimes preferred to use inert arc in the root pass for better control of the weld reinforcement and burn-through.

The use of peening to relieve stress between passes was reported by three fabricators; however, most fabricators prefer not to use peening because it is reported to promote the formation of sigma phase during heat treatment and exposure to elevated temperatures.[7] Peening was reported by Scheil and Schmitz to affect the ductility of Type 347 welds only with regard to the amount and distribution of sigma formed during heat treatment.[8] Larger particles of sigma in a segregated pattern are more effective in lowering ductility than small widely dispersed particles.

Preheat is currently being used by only two of the fabricators visited during the survey. The preheat is in the range of 200–300° F and is believed to be beneficial in the prevention of root cracking. Preheats of up to 1000° F have been used in the past, and were felt to be helpful in preventing base metal cracking difficulties; however, tests on heavily restrained pipe welds using the 1000° F preheat showed more weld metal defects than tests using a 200° F interpass temperature. It was not believed that the 1000° F preheat in itself was responsible for the larger number of defects but rather to the discomfort to the welder which makes it difficult to maintain good control over the molten weld pool.

Inert Arc Welding

The factors involved in welding with inert gas shielding are similar to welding with flux-coated electrodes from the standpoint of cracking difficulties, viz., dilution effects, C/Si ratio, ferrite content, C/Cb ratio and the effect of restraint.

For welding of thin materials the inert arc method of welding is advantageous from the standpoint of control over bead size and shape, weld reinforcement and speed of welding.

The inert arc method has a decided disadvantage in that greater amounts of dilution are usually encountered, thereby making the ferrite balance difficult to control, and causing variations from bead to bead; for this reason most fabricators are not using this method for production welding of other than sheet material. However, one fabricator reported that he had welded production jobs in Type 347 in thicknesses up to 1 in. without difficulty using the consumable electrode type of inert arc welding under the following conditions: $^1/_{16}$-in. diameter core wire, 30–32 v, 300 amp, with a travel speed of 20–30 ipm. Core wire is specified to produce ferrite in the weld deposit.

All but one fabricator who are inert arc welding with helium or argon without filler metal reported occasional cracking difficulties. The severity of cracking seemed to vary from heat to heat, with no difficulty encountered in some heats. The difficulty was believed to be encountered most frequently in heats which when fused by the arc gave fully austenitic weld deposits. The use of slower welding speeds, setups which reduced the amount of restraint across the weld and which utilize the "shear drag" as filler metal were found to reduce the tendency for these welds to crack but as yet the difficulty has not been entirely eliminated.

One fabricator reported no difficulty in depositing the root pass by inert arc without filler metal in circular seam welds which joined the head and shell of several small vessels. Welding practice was as follows:

1. Head and shell tacked together using Type 347 covered arc-welding electrodes.
2. Tacks ground so that minimum of tacking remained.
3. Interior of vessel purged with argon.
4. With a slight positive pressure of argon maintained in the vessel the abutting edges were autogenously welded with an argon-shielded thoriated tungsten electrode. The weld was accomplished by holding the inert arc torch in a horizontal fixed position and rotating the vessel.

In view of the difficulties encountered by other fabricators in inert arc welding without filler metal it was thought by the writer that some metallurgical explanation could be found.

It was found that when the austenitic region of the constitution diagram for wrought stainless steels is superimposed on the constitution diagram for stainless steel weld metal, it overlaps into the partially ferritic region (Fig. 10).[14] From a calculation of the chromium and nickel equivalents of the 13 heats of material used on this job it was found that of these 13 heats, 12 fell in this overlap area. On this basis it was reasoned that although the microstructure of the base material may have originally been fully austenitic it would, when remelted, now be governed by the constitution diagram for weld metals and would therefore contain ferrite in the microstructure and be in the condition least susceptible to cracking.

A measure of confirmation of this hypothesis was seen in the report of another fabricator who found that when a metallographic examination of a weld bead made by passing a Heliarc torch over a sample of sheet material showed ferrite in the microstructure, the weldability was good; however, when this bead showed a fully austenitic microstructure the weldability was poor.

It is suggested that if back-up rings could be selected from compositions in this range the effect of dilution in the root pass may be reduced.

A study of the effect of composition on weldability using the atomic hydrogen process gave an indication that silicon content is important for good weldability; for this reason one fabricator specified a minimum of 0.5% silicon for Type 347 sheets to be welded with atomic hydrogen. The 0.5% silicon content is not a clear-cut dividing line, although most heats above this silicon content showed good weldability and most heats below 0.5% silicon showed poor weldability.

A calculation of the chromium and nickel equivalents of the compositions used in these atomic hydrogen

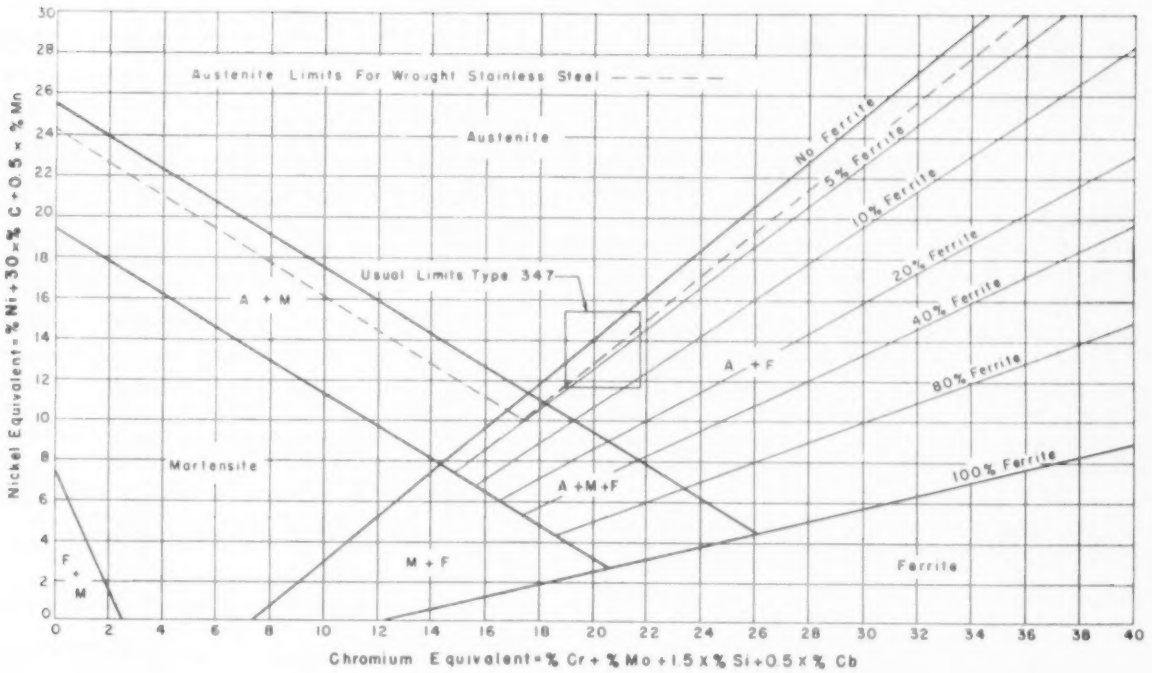

Austenite Limits For Wrought Stainless Steel
Austenite
Usual Limits Type 347
A + M
Martensite
A + M + F
M + F
A + F
Ferrite
F + M
No Ferrite
5% Ferrite
10% Ferrite
20% Ferrite
40% Ferrite
80% Ferrite
100% Ferrite
Nickel Equivalent = % Ni + 30 x % C + 0.5 x % Mn
Chromium Equivalent = % Cr + % Mo + 1.5 x % Si + 0.5 x % Cb

Fig. 10 Constitution diagram for stainless steel weld metal by Anton L. Schaeffler

Austenite limits of wrought stainless steel superimposed on the constitution diagram for stainless steel weld metal. Usual limits for Type 347 are indicated by the rectangle.

weldability tests failed to show the correlation between weldability and alloy balance which was seen in the case cited above.

Submerged Arc Welding

Submerged arc welds in Type 347 steels made with filler rod and flux of standard analyses have been shown to be unsatisfactory from the standpoint of microcracks and fissures. The welds were heterogeneous and cracks were formed in the ferrite depleted areas.[4] Substantial losses in chromium and columbium are reported to occur in passing through the arc using this method and were found to affect markedly the corrosion resistance of these alloys.

Successful welds were reported to have been made by submerged arc by adding powdered metals to the flux[11] or by selecting filler wire high in chromium and columbium contents to offset the losses which occur during welding. These losses if not compensated for impart susceptibility to cracking and lower corrosion resistance. However, because of the technical difficulties involved none of the fabricators visited reported the use of submerged arc welding on Type 347 steel on a production scale.

Suggested Lines of Research

The various fabricators visited during the survey were asked what type of information they felt it would be desirable to have in connection with the welding of austenitic stainless steels and Type 347 in particular. The following is a list of the lines of research which it was felt needed to be investigated.

1. Laboratory tests which reproduce production difficulties.
2. Effect of restraint.
3. Joint design.
4. Welding techniques.
   (*a*) Effect of preheat.
   (*b*) Stringer vs. weave bead technique.
   (*c*) Electrode size.
   (*d*) Welding current.
5. Effect of stress relieving on mechanical properties and cracking during stress relief.
   (*a*) Temperature.
   (*b*) Time.
   (*c*) Heating and cooling rates.
6. Base metal characteristics.
   (*a*) Grain size.
   (*b*) Carbide, nonmetallic inclusion and phase segregations.
   (*c*) Variations in composition.
7. Electrode variations.
   (*a*) Coating types.
   (*b*) Austenitic vs. partially ferritic microstructure.
   (*c*) Effect of composition.

(*d*) Micro and hot short cracking.

8. Effect of service temperatures.
9. Effect of thermal shock.
10. Dissimilar metal welding.

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Selected Bibliography

1. Rozet, David, Campbell, Hallock C., and Thomas, R. David, Jr., "Effect of Weld Metal Composition on the Strength and Ductility of 15% Cr – 35% Ni Welds," THE WELDING JOURNAL, **27** (10), Research Suppl., 481-s to 491-s (1948).
2. Carpenter, O. R., and Jessen, N. C., "Some Factors Controlling the Ductility of 25% Cr – 20% Ni Weld Deposits," *Ibid.*, **26** (12), Research Suppl., 727-s to 741-s (1947).
3. Scheil, M. A., and Schmitz, F., "Symposium on Nature, Occurrence, and Effects of Sigma Phase." Presented at 53rd Annual Meeting of ASTM, June 27, 1950. ASTM Special Technical Publication No. 110.
4. Emerson, R. W., and Morrow, Matthew, "Welding High Temperature Austenitic Steel Piping," THE WELDING JOURNAL, **26** (1), Research Suppl., 15-s to 39-s (1951).
5. Carpenter, O. R., Jessen, N. C., Oberg, J. L., and Wylie, R. D., "Some Considerations in the Joining of Dissimilar Metals for High Temperature, High Pressure Service." Presented at the 53rd Annual Meeting of ASTM, June 29, 1950.
6. Rapatz, F., "Weldability of Chromium-Nickel Steels Resistant to Chemical Agents," Berg-und Huttenmannische Monatshefte, **95**, No. 12, 368–370 (1950). (Brutcher Translation No. 2744).
7. Thielsch, Helmut, "Physical Metallurgy of Austenitic Stainless Steels," THE WELDING JOURNAL, **30** (12), Research Suppl., 577-s to 621-s (1950).
8. Thomas, R. David, Jr., "Crack Sensitivity of Chromium-Nickel Stainless Weld Metal," *Metal Progr.*, **50**, 474–479 (1946).
9. Thielsch, Helmut, "Welding Processes and Procedures Employed in Joining Stainless Steels" (to be published).
10. WELDING HANDBOOK, Third Edition, AMERICAN WELDING SOCIETY, New York (1950), p. 26.
11. Bloom, F. K., *et al.*, "Austenitic Chromium-Nickel Stainless Steels," *Ibid.*, pp. 648–671.
12. Bishop, E., and Bailey, W. H., "Weld Metal Properties and Welding Characteristics of Two Austenitic Steels Used for Gas Turbine Rotors," Symposium on High Temperature Steels and Alloys for Gas Turbines, Iron and Steel Institute (1951).
13. Aplblett, W. R., and Pellini, W. S., "A Recording Dilatometer for High Temperatures," *Trans., Am. Soc. Metals*, **44**, 1200–1214 (1952).
14. Schaeffler, A. L., Arcos Corp. files.

Fabricators and Contributors

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Sandblasting and Annealing to Improve Flame-Cut High-Tensile Steel

(*Continued from page 402-s*)

torches were moved back and forth over the length of the cut to heat the specimen uniformly to a dull red. The time of heating and cooling was much longer than for No. 7. The tensile strength was 137,000 psi with 38% reduction of area. The maximum hardness at the cut edge was only 400 Vickers.

The fatigue limit for oxygen-cut specimens was 28,000 psi compared with 54,000 psi for machined surfaces. The specimens stress relieved at 1040 and 1080° F, as well as those heated red hot by torches had even lower fatigue strength than as-cut specimens. The sandblasted specimens had the same high fatigue strength as machined surfaces. The sandblasting was done with relatively coarse sand until the drag lines disappeared. The blasted surfaces had the same appearance as the surface of the plate. Three factors account for the high fatigue limit of the sandblasted specimens: (1) sandblasting removes the layer about 0.004 in. deep containing hair cracks; (2) sandblasting removes the fine drag lines perpendicular to the stress; (3) sandblasting deforms the surface plastically, and creates residual compressive stresses which improve the tensile fatigue strength.

These tests show that torch heat treatment to a dull red is desirable for flame-cut high-tensile steel if toughness is required, but that sandblasting is called for if high fatigue strength is required and toughness is unimportant.

The Use of Structural Quality Steel in Pressure Vessels

An interpretive report prepared under the auspices of the Materials Division of the Pressure Vessel Research Committee on the possible use of carbon steel plates of structural quality in pressure vessels in time of material shortages

by I. E. Boberg

INTRODUCTION

IN REVIEWING the factors leading to the use of carbon steel plates of structural quality* in pressure vessels, it appears obvious that the greatest motivating force has been that of economy, since these materials cost less than boiler plate steel of flange or firebox quality. Also there has been much speculation as to whether a possible scarcity of the boiler plate steels would force a switch to the plate steels of structural quality in a time of material shortages such as could be created by another serious emergency.

It is the purpose of this report to evaluate the available structural quality steels not only as to comparative properties and availability, but also as to their suitability for welded pressure vessel construction. While the economics of the situation will not be discussed in detail, it is impossible to ignore that phase of the subject entirely. If a particular structural quality steel offers neither economy nor probable availability, there is little reason to consider its substitution for an approved boiler plate steel of flange or firebox quality.

In addition, a comparison with some of the commonly used boiler plate steels together with a summary of past experience, may aid in a better understanding of the limitations and possibilities involved in the use of structural quality steel for pressure vessels.

AVAILABILITY

In an era of national emergency, it is probable that some of the pressure vessel plate steels would be in short supply since a number of plate steel specifications require a killed steel which necessitates hot topping, more time in the soaking pit, more time for ingot heating and additional slab conditioning operations. Furnace and rolling capacity would have little effect because quantity, size and thickness limitations would be essentially the same for any steel being considered for a particular purpose. A major shipbuilding program would intensify the situation, since the trend is toward killed steel in welded ship construction, particularly in the heavy plates.

Thus it can be said that there is almost certain to be a shortage of fully killed steel for civilian use during a period of emergency. It is significant to note that some of the higher strength structural steels are also fully killed and hence subject to the same manufacturing limitations as the fully killed boiler plate steels. On the other hand, some of the boiler plate steels are semikilled or rimmed, depending on the producer, and would be as available as the nonkilled structural steels.

A GENERAL COMPARISON OF STRUCTURAL QUALITY PLATE STEELS WITH BOILER PLATE STEELS OF FLANGE OR FIREBOX QUALITY

Before discussing particular specifications, it would be well to consider the principal differences between structural steel plates and boiler steel plates. Basically, it is difficult to draw any clear lines of distinction because both categories include fully killed steels as well as semikilled or rimmed steels.

The fully killed structural steels are of little interest in this discussion because they afford neither the incentive of availability nor low cost. Obviously it would be futile to compare the fully killed boiler steels with the rimmed or semikilled structural steels. In addition to greater uniformity, the fully killed steels offer other advantages such as greater notch toughness, particularly if ordered to fine grain practice.

Certainly one of the principal differences between

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* The term "Quality" is indicative of the condition of the material. When used in this sense, the term "quality" refers to the characteristics of the materials and corresponds in general to the words "class," "kind" or "grade."

structural steel plates and boiler steel plates is in quality control as expressed by the number and severity of test requirements. Perhaps the best way to illustrate the difference is to compare the general requirements for structural steel (ASTM A6–52aT) with the similar general requirements for boiler plate steel (ASTM A20–52T).

Aside from specific limits on carbon, manganese and silicon, it can be said that, in general, the extent of chemical control as expressed by the ladle analysis is essentially the same except that flange and firebox qualities of boiler plate steel usually have more restrictive limits for phosphorus and sulfur. The only exceptions are flange quality in the rimmed and semi-killed steels such as ASTM A285 and A30 which do not carry a carbon restriction. It should be noted, however, that in the check analysis which the purchaser is privileged to make, all boiler plate steels including the foregoing exceptions, must meet lower limits on phosphorus and sulfur than do the structural plate steels.

Permissible variations in thickness, etc., are identical, provided the structural steel plates are ordered to thickness and not to weight per square foot.

The methods of testing these two types of steels for mechanical properties are quite similar; the major differences are in the number of tests and the stipulated location for test specimens.

For plate steels of structural quality, only two tension and two bend tests are required from each heat, which may represent as much as 150 tons of steel. For heats of less than 30 tons, only one tension and one bend test are required.

For plate steel of flange quality, one tension and one bend test are required for each plate as rolled.

For plate steel of firebox quality, two tension tests, one bend test and one homogeneity test are required from each plate as rolled.

Another major difference between these specifications is in the permissible methods of repairing defects, which in turn infers certain precautions in manufacture as well as in conditioning the slabs prior to rolling. Under ASTM A20–52T, plate steels are permitted to be conditioned by "the removal of surface imperfections or depressions on either surface of the plate by grinding, provided the ground area is well flared and grinding does not reduce the thickness of the plate as-rolled below the permissible minimum thickness in inches."

ASTM A6–52aT permits defects in structural plate steels to be repaired in the same manner, but in addition permits the repair of surface defects by chipping followed by the deposition of weld metal under certain limiting conditions. The principal limits are that not more than 2% of any plate surface and that no defect deeper than 20% of the plate thickness shall be repaired in this manner.

A SURVEY OF AVAILABLE SPECIFICATIONS FOR STRUCTURAL QUALITY STEEL PLATES

Before any conclusions are drawn, the available specifications for structural steel plates should be considered.

ASTM designation A6–52aT lists the following structural specifications that include rolled plates:

A7 — Steel for Bridges and Buildings
A8 — Structural Nickel Steel
A94 — Structural Silicon Steel
A113 — Structural Steel for Locomotives and Cars
A131 — Structural Steel for Ships
A242 — Low-Alloy Structural Steel
A283 — Low and Intermediate Tensile Strength Carbon Steel Plates of Structural Quality.
A284 — Low and Intermediate Tensile Strength Carbon-Silicon Steel Plates for Machine Parts and General Construction

Some of the steels covered by these specifications are either beyond the scope of this paper or obviously unsuited for welded pressure vessel construction, while other steels will not be considered because the incentives of economy and availability are lacking.

A242 is beyond the scope of this report, since it covers low-alloy, high-strength steels. Likewise, A8 will not be considered because this specification describes an alloy steel.

On the premise that a structural steel for use in a pressure vessel must be readily weldable, A94 may be eliminated since it contains 0.40% carbon, max. It also lacks the incentives of low cost and probable availability.

A284 appears to be quite usable. Since it is a fully killed steel, it might be considered a fundamentally better steel than A285 except for the number of requirements. However, the fact that it is a fully killed steel may reduce its availability and the cost incentive is absent.

Thus, the structural type field is limited to A7, A113, A131 and A283. Until 1951, there was little difference, except tensile range, among these four steels as listed in 1949 ASTM Standards. A131–52T, however, represents a radical change from A131–49T. Formerly, this specification contained chemical limitations only on phosphorus and sulfur, but A131–52T now contains in addition a maximum limit on carbon and a range for manganese for plates over $\frac{1}{2}$ in. in thickness. Furthermore, for plates over 1 in. thick, 0.15 to 0.30% silicon is specified with the added stipulation that they be made to fine grain practice. Therefore, for these thicker plates, the incentives of economy and probable availability are absent, but this specification is unique in that it pursues the logical course of increasing quality as thickness increases. The lower carbon and relatively higher manganese content and the fine grain practice in heavier thicknesses are believed to increase notch toughness. Although there is little experience as yet with this improved ship hull steel in the construction of tanks and pressure vessels, it appears worthy of consideration.

For Specifications, A7, A113 and A283, there seems

to be little to recommend A113 over the other two. Certainly A7 and A283 are the two most widely used of all structural plate steels.

It should also be noted that tank plate steel can be ordered to A7 and still is to some extent. Grade D was included in A283 at the request of the fabricators since its strength level is the same as A7, thereby providing one specification for use in ordering steel plates for tank construction. In so far as tank plate steel is concerned, there seems to be no reason for specifying A7, but those who continue to do so should probably stipulate that it be made by the open-hearth process.

Thus it is concluded that, of all presently available structural plate steels with which there has been considerable experience, ASTM A283 may show the greatest promise for extended usage. This conclusion does not open a vast new field, because this material is now permitted for limited use in pressure vessels by both the API-ASME and the ASME Codes.

A283 is available in Grades A, B, C and D, with specified minimum tensile strengths of 45,000, 50,000, 55,000 and 60,000 psi, respectively. Grades A and B have been extensively used where forming operations are relatively severe and tensile strength is of secondary importance. Grade D is not commonly used because its higher strength renders it sightly less suitable for cold working and slightly less weldable than Grade C, and there is no economic advantage gained through its use because it is not credited with a higher allowable unit stress than is given in the Codes for Grade C.

The steel now known as A283–52T Grade C is the structural steel that has been most widely used in pressure vessels. The term "now known as" is used advisedly since essentially the same steel has, in the past, been designated as A7-33 and A10. The reader should not confuse A7-33 with A7–52T. After 1933, the tensile range of A7 was increased from 55,000–65,000 to 60,000–72,000 psi and the old A7 became A10, and finally A283 Grade C.

A SPECIFIC COMPARISON OF A283 GRADE C AND A285 GRADE C

As has already been stated, it would be futile to compare A283 Grade C with such fully killed plate steels as A201.

On the other hand, a direct comparison of the structural steel A283 Grade C with the most widely used boiler plate steel, namely A285 Grade C, appears to serve a better purpose.

In making this comparison, it is not the author's intention to discredit A285 as a pressure vessel steel. The extra cost of the closer metallurgical control and more extensive testing afforded by A285 over A283 Grade C is relatively low. Even though the two steels are essentially identical in production practice, the closer control required to meet the more exacting test requirements for A285 may well have its advantages under the accelerated demand for steel during periods of great national emergency.

The author's primary purpose in making such a comparison is to show why responsible fabricators do not normally hesitate to use A283 Grade C, as an equal to A285 Grade C, within certain limits, when the construction specifications permit its use.

Once a structure is successfully completed, it would be difficult to establish any difference between one of A283 Grade C and another of A285 Grade C. There is little reason to believe that tensile strength or ductility would differ. There is no evidence to indicate that there is any difference in notch toughness. It appears that at least one principal value of the closer metallurgical control for A285 is to assure the fabricator that he receives material with a greater degree of uniformity in chemical composition which contributes to better cold forming characteristics and better weldability.

The widespread and successful use of A283 Grade C in tank work of all sorts will refute any contention that it cannot be readily formed and welded. A large proportion of all elevated tanks, water standpipes, oil storage tanks and nonpressure tanks of all descriptions involving both dishing and rolling, are constructed of A283 Grade C. Frequently, Grades A and B are used for severe cold forming.

If the steel producer permitted carbon to run too high, and sulfur to reach the limit of 0.05%, and if the sulfur were concentrated in segregations, admittedly the fabricator would have difficulties with no recourse under the specifications for A283 Grade C. The facts are, however, that this should never happen, partly because of the integrity of the producer and partly because the specified limitations on tensile range, ductility and bend test automatically set definite limits on composition and steelmaking practice.

	Structural plate, A283 Grade C	*Boiler plate — A285 Grade C flange*	*Boiler plate — A285 Grade C firebox*
Carbon, max., 3/4 in. and under, %	None	None	0.25
Carbon, max, 3/4 in. to 2 in., %	None	None	0.30
Manganese, max, %	None	0.80	0.80
Ladle analysis:			
Phosphorus, acid max, %	0.06	0.05	0.04
Phosphorus, basic max, %	0.04	0.04	0.035
Sulfur, max, %	0.05	0.05	0.04
Check analysis:			
Phosphorus, acid max, %	0.075	0.05	0.04
Phosphorus, basic max, %	0.05	0.04	0.035
Sulfur, max	0.063	0.05	0.04
Tensile, psi	55,000–65,000	55,000–65,000	55,000–65,000
Yield point, min, psi	30,000	30,000	30,000
Elongation in 8 min, %	23	24	25
Elongation in 2 min, %	24	27	27
Bend test, ratio of inside diam of bend to thickness:			
3/4 in. and under	Flat	1	1
Over 3/4 to 1 in.	1/2	1	1
Over 1 to 1 1/2 in.	1	1 1/2	1 1/2
Over 1 1/2 to 2 in.	2	2	2

For convenience in comparing A283 Grade C with A285 Grade C in both flange and firebox qualities, a summary of the principal properties is given on the previous page.

While it may appear that A283 Grade C has more stringent bend test requirements, it should be noted that the bend-test specimens are taken longitudinally, whereas the bend-test specimens for A285 are taken transversely.

In reaching a conclusion, the user of plate steel must necessarily rely on his own experience. For example, it will be obvious from the above tabulation, that if high sulfur is being experienced in A283, it would be advantageous to specify A285 in firebox quality.

Perhaps some of the existing uncertainties could be clarified if there were a way in which the steels under discussion could be more closely defined as to steelmaking practice. Quite correctly, steel specifications avoid any mention of processing details, other than the designation open hearth, electric furnace and a restriction on Bessemer. The process is controlled rather by chemical and mechanical properties. In the case of the steels under discussion, they may be made rimming, semikilled or killed with resulting variations in the characteristics of the material. As long as this situation exists, the appraisal of steel for pressure vessel applications is necessarily based on the experience and judgment of the designing engineer.

Perhaps the steel producers can devise an acceptable means of defining whether steel is rimmed or semikilled, and define what is meant by semikilling, just as full killing is now governed by a specified silicon content. Even description of full killing by a minimum silicon content is inadequate for steels to be used for high temperature and low temperature applications, since a steel is frequently killed with aluminum as well as silicon. Aluminum, when added in sufficient amounts, tends to make the steel fine-grained, improving its notch toughness and hence its performance in low temperature applications. However, aluminum tends to increase the susceptibility to graphitization and to lower the creep strength of the material, thereby rendering it less suitable than coarse-grain material for elevated temperature applications. The ASME Boiler Construction Code has recognized this problem by the insertion of a footnote in the table of allowable working stresses for the Unfired Pressure Vessel Code, stating:

"For service temperatures above 850° F it is recommended that killed steels containing not less than 0.10% residual silicon be used. Killed steels which have been deoxidized with large amounts of aluminum and rimmed steels may have creep and stress-rupture properties in the temperature range above 850° F, which are somewhat less than those on which the values in the above table are based."

TRENDS AND CURRENT PRACTICE

Vessels operating at pressures higher than 15 psi fall within the range covered by the pressure vessel codes. General practice is to construct such vessels in accordance with code rules governing materials and unit stresses, regardless of whether or not the vessel is to be stamped with a code symbol. In effect, this means that the structural plate steels such as A283 are rarely used because the allowable code unit stresses are 8% lower than those permitted for corresponding grades of A285.

Vessels operating at pressures of 15 psi and less are not covered by any existing construction code, although API is working on the formulation of one. In this range of pressures, the structural plate steel A283 Grade C has been rather widely used because many designers have had no hesitation in utilizing it at the same unit stress permitted by code for A285 Grade C.

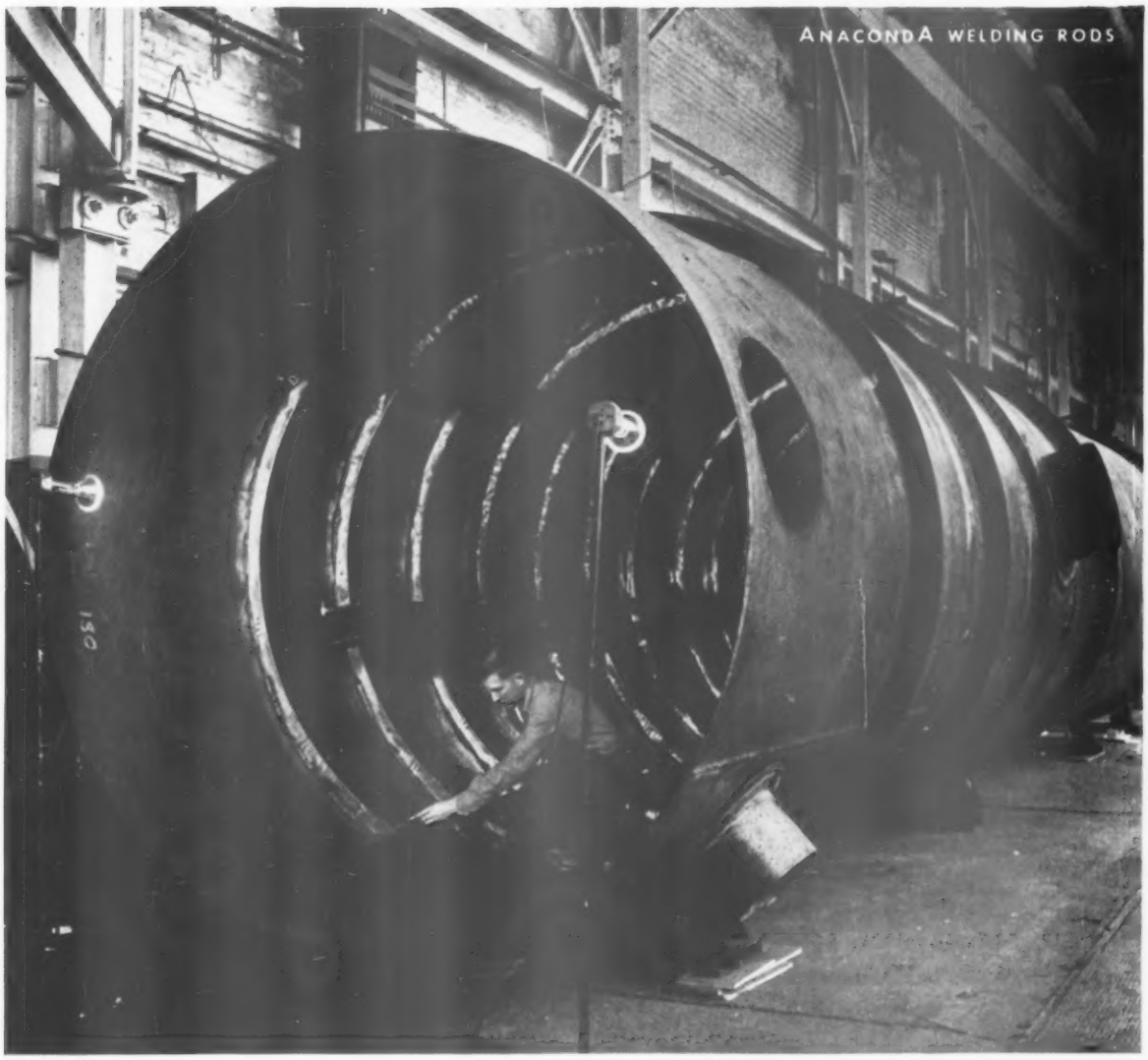
Higher strength structural steel plates such as A283 Grade D are not widely used in pressure vessels. Designers are hesitant to take advantage of the increased strength because there is no carbon limit and if the plates fall in the upper part of the tensile range, welding, cold working and the effects of cold working may present problems.

The new ship hull steel A131–52T is receiving some attention in oil tank construction and may well offer an intermediate solution for pressure vessels. The aim of this specification appears to be an optimum relationship between notch toughness and cost as thickness varies.

The current trend in the heavier pressure vessels is toward the use of A201 Grade B*. The increase in strength of A201 Grade B over that of A285 is not enough to appreciably affect cold forming, and notch toughness is superior particularly if ordered to fine grain practice. It has been found that where stress governs the design of all parts of the structure, the saving in fabrication and welding, due to the thinner plates, will just about offset the added cost of material. This situation makes the trend toward A201 seem natural and logical.

The same advantage in the use of A201 applies, to a lesser degree, to the lighter pressure vessels in which the thicknesses of large portions of the vessel are determined by desirable minimums rather than stress. In such cases, the use of A201 is uneconomical since material costs go up while the fabrication and welding costs remain the same.

* In the discussion which follows, the same trend applies to A212 as to A201, except that A212 is not commonly used for field erected pressure vessels.



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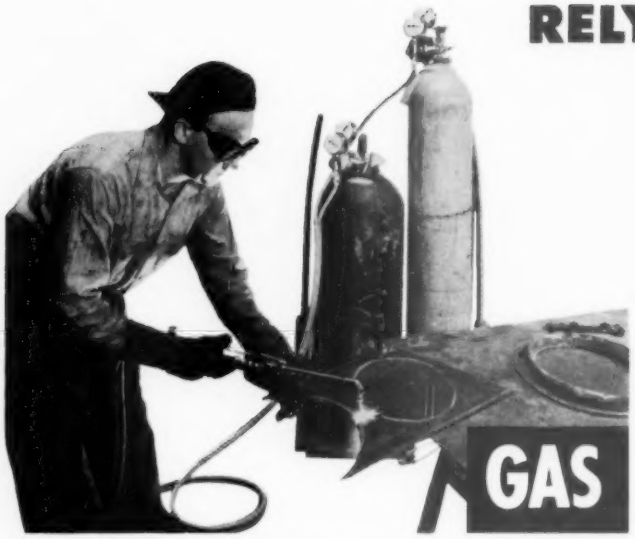

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